COMPARISON OF HUMIC ACID, DEXTRIN AND CARBOXYMETHYL CELLULOSE AS MODIFYING REAGENTS IN COAL AND COAL PYRITE FLOTATIONS

Final Report

by

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ABSTRACT

Significant liberation of pyrite from DEVCO coal has been shown to take place only when the top size is reduced below 200μm.

Examination of the effects of the modifiers humic acid, carboxymethyl cellulose (CMC) and dextrin on the flotation of the coal indicates that the mechanism of action of the modifiers differs significantly. Humic acid affects coal flotation predominantly due to electrical effects. The contribution of electrical effects is negligible in the case of dextrin while CMC acts in a manner different to both. As a result of these differences, dextrin may pronouncedly affect coal floatability independent of the pH. The behaviour of carboxymethyl cellulose in coal flotation systems depends strongly on the pH.

The depressant effect of humic acid on the flotation of coal depends not only on the reagent combination used, but also on the time of conditioning in the stage preceding the flotation. Appropriate use of the discovered time effect may greatly improve the selectivity of flotation with humic acid.

The use of dextrin in a two-stage reverse flotation of DEVCO -75μm coal results in inferior selectivity compared to conventional flotation with humic acid and carboxymethyl cellulose.

INTRODUCTION

Coal preparation consists mostly of gravity concentration, supplemented to some extent by flotation and completed predominantly by screening and solid/liquid separation auxiliary processes. While gravitational methods provide good separation selectivity at coarser sizes, they become inefficient with decrease in size of treated material.

Recent environmental regulations have necessitated the progressive cleaning of thermal coal. To achieve a high recovery of combustible material and maximum reduction in pyritic sulphur, liberation of coal from its associated high-ash and high-sulphur gangue is needed and many coals require very fine grinding for pyrite liberation. Such fine feeds can be cleaned only by flotation and three modifications of this process have been developed to deal with high sulphur coals:

(a) Flotation with starvation reagent additions which take advantage of differences in the rate of flotation of coal and of pyrite particles under such conditions;

(b) Depression of pyrite in the alkaline pH range, while floating coal;

(c) Two-stage reverse flotation, in which after the first conventional flotation stage separating the coal and pyrite from the high-ash particles, coal is depressed with dextrin in the second stage and pyrite is floated off with xanthate.

All of them are, however, far from successful in industrial applications.

During the last two years CANMET has sponsored a research program at the University of British Columbia in which the effects of humic acid as well as dextrin and carboxymethyl cellulose used as modifiers, have been studied in attempts to separate coal from pyrite.

Adsorption interactions of humic acid involved in the coal flotation process are of great importance. This year the research program has been divided into four major divisions:

(a) Petrographic study of pyrite liberation during comminution of the DECCO high sulphur coal;

(b) Electrokinetic measurements and small scale flotation experiments with the low sulphur bituminous coal;

(c) Adsorption and electrokinetic studies on DEVCO pyrite and coal.

(d) Bench scale flotation of the low-sulphur bituminous and high-sulphur DEVCO coals.

PETROGRAPHIC STUDY OF PYRITE LIBERATION DURING GRINDING OF THE DEVCO COAL

Although the study on liberation of coal from pyrite has not been envisaged in this year's research program, some experiments on the effect of comminution on pyrite liberation have been conducted and these results are discussed in this section. This liberation work is continued outside the scope of this research project.

Samples of DEVCO high sulphur coal from Nova Scotia, as supplied by CANMET, Ottawa, were used in the experiments.

In the first series of experiments the coal was crushed and repeatedly sieved through a 500 μm screen with recrushing oversize fraction to obtain finally, 100 percent below 500 μm material.

In the second series the same procedure was followed but 212 μm screen was used and crushing was carried out until 100 percent was passing that screen.

In the third series material 100 percent below 75 μm was prepared by dry grinding. These three samples will be further referred to as: DEVCO coal -500μm, DEVCO coal -200μm, and DEVCO coal -75μm. They were subsequently siezed by sieving and analysed for ash and sulphur. (Table 1).

The three ground samples characterized in Table 1 were further examined by petrographic methods to determine the mode of occurrence, abundance and degree of liberation of pyrite from the organic matter. From an initial examination of the samples it was apparent that the amount of liberated pyrite varied so little between and within the sample suites that visual approximations were not reliable and count analysis was necessary. The methods used, the relative abundance of pyrite forms, together with some general observations, are reported below.

Methods

All samples were formed into pellets using transoptic powder and polished using standard procedures. The samples were examined using coal petrographic techniques and point counted. On all samples at least 700 points were counted and on most samples over 1000 points were counted. The modal analysis was performed on an ash free basis but included microscopically visible pyrite. The size of the pyrite was determined using an eye piece equipped with a micrometer.

Mode of Occurrence of the Pyrite

Pyrite occurs in three discrete forms in the coal samples:

(1) a massive anhedral to subhedral form of pyrite ranging from 50 to 250μm in size and averaging about 100μm;

(2) a framboidal form of pyrite which averages about 20μm in size; and

(3) very fine pyrite referred to here as "blebs" that average 2μm.

The coarsest coal fractions examined (500 to 425μm) are considered to approximate most closely the relative abundance of the different pyrite forms in the raw coal. In the sample under study, there was about 50 percent massive pyrite, 40 percent framboidal pyrite and 10 percent blebs. In other, finer size fractions of DEVCO coal, the relative abundance of the pyrite forms was found to be more strongly skewed because of the uneven size distribution of the pyrite on sieving. It is noteworthy that sieving was not completely effective because blebs which should have been restricted to the -45μm fraction were found in all fractions.

All forms of pyrite have been found to be predominantly associated with (estimated greater than 95%) and intergrown among various forms of vitrinite.

In some vitrinite grains the pyrite clearly infills cell lumens, but in most grains the pyrite appears randomly distributed. Pyrite is rarely associated with liptinite group macerals or inertinite and semi-inertinite. Almost no pyrite was found associated with mineral matter although polishing may have removed some mineral matter. Selected photomicrographs illustrating these observations are shown in Figures 1 to 8.

Degree of Pyrite Liberation

The relative abundance of pyrite, liberated pyrite, percentage of non-liberated pyrite and the relative abundance of the different forms of pyrite are ahown in Tables 2, 3 and 4. From the tabulations the following observations can be made.

1) The amount of non-liberated pyrite as a percentage of total pyrite decreases in each finer sieve fraction in the samples examined with the exception of the -45μm fraction.

2) Massive pyrite is completely liberated in the -75μm fractions of both coarser samples.

3) The relative abundance of non-liberated framboidal pyrite declines with sieve size in all three suites with the exception of the -45 fraction of the -500 sample.

4) There is no trend in degree of liberation with size of the pyrite blebs in either sample suite.

5) There is no significant difference in the absolute amount of liberated pyrite between the 500 and 200 series of samples. There is more non-liberated pyrite present in each size fraction of the 200 series than in the 500 series (opposite to what would be expected).

6) In the -75μm sample: 30.9% pyrite was found not to be liberated in a -75 + 53μm fraction, 19.1% in a -53 + 38 fraction and 15.8 in a -38 fraction. This indicates that a drastic increase in the amount of liberated pyrite occurs when a top size of the DEVCO coal is reduced from 200 to 75μm.

ELECTROKINETIC MEASUREMENTS AND SMALL SCALE LAB FLOTATION EXPERIMENTS

Electrokinetic Measurements

The microelectrophoresis apparatus, Zeta-Meter, was used to determine the zeta potential of kerosene and fuel oil droplets, and Fording Coal particles as a function of pH and in the presence of the tested modifying reagents.

A drop of kerosene was emulsified in 100 ml of the test solution for one minute in a blender. The Zeta Meter cell was filled with the emulsion and the zeta potential measured in the usual way. Similar measurements have also been carried out with the Gulf Fuel Oil mixture containing four parts of fuel oil #2 to one part of fuel oil #6[1].

The Fording coal sample described by J. Leja et al[2] and Yarar and Leja[3] was also used in the experiments. The sample from the 11.6 m seam containing 17% ash was crushed below 500μm and concentrated by means of a superpanner. Clean coal samples were dried at 40-50°C, sized, and stored in closed flasks. They contained 7% ash. Before the zeta potential measurements, roughly 0.1g samples were ground in a mortar and pestle and equilibrated for 20 minutes with a given solution before filling the cell and taking measurements.

Figure 9 shows the effect of humic acid concentration on the zeta potential of kerosene droplets in distilled water and in 5×10^{-3}M KCl solution. As can be seen, an increase in humic acid concentration makes the zeta potential values of kerosene drops more negative; the zeta potential value is even more negative in 5×10^{-3}M KCl solution. These observations agree well with our previous results obtained with graphite.[4]

Figure 10 shows the effect of pH on zeta potential of kerosene droplets emulsified in distilled water, or in 20 ppm solutions of dextrin, carboxymethyl

cellulose or humic acid. Humic acid and carboxymethyl cellulose, both anionic polyelectrolytes, make zeta potential values more negative over the whole pH range. In contrast, dextrin does not effect the zeta potential of kerosene droplets at all.

The results of the measurements carried out with the Gulf fuel oils #2 and #6 mixture are given in Figure 11. Our results for the kerosene and Gulf fuel oils in distilled water agree quite well with those reported by Wen and Sun[1]. The presence of MIBC which is used in our flotation experiments does not introduce, as expected, any significant effects (Figure 12).

The effect of the tested modifiers on the zeta potential of Fording coal is shown in Figures 13, 14 and 15. As seen, the same trend is observed as in the experiments with kerosene and Gulf fuel oil. Whereas dextrin does not have any effect on the zeta potential of coal, both humic acid and carboxymethyl cellulose make the zeta potential of coal much more negative.

Small Scale Flotation Experiments

In our flotation experiments, 2 g of -150 + 63 m Fording coal, cleaned on superpanner, was conditioned with 200 ml of distilled water for 20 minutes. An appropriate volume of MIBC solution in distilled water was then added and stirred for 3 minutes, then humic acid solution was introduced and stirred for another 5 minutes. The pulp was allowed to stand for 5 minutes, the settled suspension of coal was placed in a Smith-Partridge cell[5] and the supernatant solution was used to fill it up. The flotation was carried out for 1 minute with a 30 ml/min. nitrogen flow. In some experiments depressants were added first; then MIBC.

Figure 16 shows the effect of modifiers and the order of adding modifier and MIBC on the flotation of Fording coal. In the case of humic acid and CMC,

depression of coal flotation is very strong if the modifiers are added before MIBC. Dextrin affects flotation strongly irrespective of the order of reagents addition. As shown in Figure 17, a combination of CMC and humic acid in the presence of MIBC may even lead to better flotation results.

Figures 18, 19 and 20 show that the floatability of the Fording coal with kerosene is affected by the modifiers. Two different procedures have been tested. In the first procedure, 2 g. of coal was conditioned with a modifier and then with emulsified kerosene. In the second procedure, one drop of kerosene (0.015 g.) has been emulsified in the solution of modifier and then added to the pulp. Figures 18 and 19 show that both humic acid and dextrin depress coal irrespective of the mode of reagents additions. CMC does not produce any significant depression in the flotation with kerosene.

The effect of pH on the floatability of Fording coal with MIBC and in the presence of modifiers is illustrated in Figure 21. As can be seen, humic acid depresses the flotation only in the acid range, while very pronounced depression over the whole pH range is observed with dextrin. CMC depresses coal floatability in the acid range, similarly to humic acid, but it promotes floatability in the alkaline range. This also explains some reported observations that CMC may hinder or enhance coal floatability depending on its concentration[6]. Our results indicate that this may also be caused by a change in pH.

Figure 22 shows floatability results obtained with kerosene emulsified in the solution of modifiers prior to introduction into a flotation pulp. Dextrin as in the previous case depresses floatability strongly irrespective of pH. Depression in 20 ppm humic acid solution, in accordance with Figure 18, is stronger than in 100 ppm humic acid solution. The effect of pH is es-

pecially pronounced when CMC is used.

The effect of modifiers on the flotation of Fording coal with Gulf fuel oils is shown in Figure 23. Two procedures have been tested: the depressants were added prior to fuel oil in the procedure A, and was emulsified together with fuel oil and than introduced to the pulp in procedure B.

The floatability of the same coal versus pH with Gulf fuel oils emulsified with the modifiers prior to addition to the flotation pulp is given in Figure 24. Almost a complete depression has been observed with dextrin and humic acid, while CMC again produced lesser depression.

Dextrin, which strongly affects coal floatability, does not affect either the zeta potential value of coal or the zeta potential of oily collector droplets. Both humic acid and carboxymethyl cellulose make the zeta potential values of oily droplets and coal particles much more negative. Yet, CMC does not depress the coal as strongly as humic acid, and in alkaline conditions it may even enhance coal floatability. These results show that the mechanism of action of the modifiers studied differs. While the effect of humic acid seems to be predominantly due to electrical effects, the contribution of electrical effects to overall results is negligible in the case of dextrin; CMC acts in a way somewhat different from the others.

ADSORPTION AND ELECTROKINETIC STUDIES ON DEVCO PYRITE AND COAL

Exploratory Flotation Experiments on the Reverse Flotation

J. D. Miller et al[7] in their recent paper, provided detailed information on the bench scale reverse flotation experiments. According to their procedure, two hundred grams of wet ground minus 48 mesh Illinois coal is conditioned at 1.6 kg/t MIBC frother for five minutes. The slurry is then transferred to the flotation cell and floated for 2 minutes at 1000 rpm stirring speed with the air flow rate fixed at 9 liters min^{-1}. The tail is filtered, dried and weighed. The concentrate is repulped with fresh water to make 2.3 liters, and conditioned for 5 minutes with enother 1.6 kg/t MIBC, then reconditioned for an additional 5 minutes with the desired amount of depressant, and another 5 minutes with potassium amyl xanthate. For the coal they tested, the best combination of pyrite collector, potassium amyl xanthate, and coal depressant, Amaizo 1706 (dextrin supplied by the American Maize-Products Company) was in the range from 0.5 to 1.0 kg/t dextrin and 0.45 kg/t KAmX. Under such conditions 79% of the second-stage feed was recovered as a clean product with a 1.22% pyritic sulphur content.

Miller's procedure has been closely followed in our preliminary bench flotation experiments. We found that in the case of DEVCO coal, 2 x 1.6 kg/t MIBC is unnecessarily high and 400 g/t MIBC is enough to float DEVCO coal efficiently in the first stage when coal is dry ground. The results are shown in Table 5 and, as seen, they are not satisfactory. We found that 800 g/t MIBC has been needed when the coal was wet ground. In all our flotation experiments carried out according to Miller's procedure, the flotation of pyrite in the second-stage was particularly poor. In the subsequent part of our work we then concentrated on the use of humic acid and carboxymethyl

cellulose. This, however, does not rule out completely the use of dextrin in the flotation of DEVCO coal. To determine the most effective reagent schedule a full factorial design of flotation tests will be required.

Adsorption and Electrokinetic Measurements

The Devco coal sample was crushed below 200μm and concentrated by means of superpanner. Clean coal and pyrite fractions were used separately in the following experiments.

The unsuccessful use of dextrin in the two-stage reverse flotation tests (Table 5), caused the stress to be placed on the use of humic acid and carboxymethyl cellulose in the following experiments.

UV spectra at 300 and 400nm as described in the 1983 report have been utilized to follow a change of humic acid concentration in the adsorption studies. Figure 25 shows the effect of pH on the humic acid concentration change after equilibrating 50 ml of 10 ppm humic acid solution with 0.5 g of DEVCO pyrite (or coal) for 60 minutes.

As seen, the concentration of humic acid decreases with time of conditioning only in the acidic pH range. In alkaline pH the concentration is higher after conditioning with DEVCO coal and DEVCO pyrite. While the adsorption seems to be responsible for the concentration decrease under acidic conditions, leaching of humic acid from the solid must be responsible for the concentration increase after conditioning; these results also indicate that our coal-pyrite separated from DEVCO coal still contained some amount of interlock coal. It is to be pointed out then that the separation of the pyrite from coal which would lead to completely liberated pyrite is not very realistic. All observations made in the experiments with coal-pyrite may then also be attributed to the presence of some amount of coal in the pyrite samples.

Adsorption isotherms of potassium amyl xanthate on DEVCO pyrite are shown in Figure 26. The adsorption is not affected by the presence of humic acid. This is also seen from Figure 27. The effect of pH on xanthate adsorption is not so pronounced as in the case of ore pyrite. On the other hand, the adsorption of humic acid on DEVCO-pyrite is clearly hindered by the large concentration of amyl xanthate. This indicates a much higher affinity of xanthate toward pyrite surfaces and is quite understable. It is surprising however, that adsorption of humic acid onto DEVCO-coal (Figure 29) is less than that on DEVCO-pyrite. As already pointed out (Figure 25) the adsorption of humic acid may be very much affected by the reverse process, that is leaching of similar substances from the solid during the experiment. This makes it impossible to draw any final conclusions from these data.

On the other hand, the results of the zeta potential measurements shown in Figure 30 are very informative. As can be seen, the zeta potential of DEVCO-pyrite is even more negative in the presence of humic acid and CMC than in the presence of amyl xanthate. Humic acid and CMC behaviour in this system is not different from that observed in the zeta potential measurements with coal (Figures 13, 14 and 15) and it is impossible to estimate the extent to which this effect is due to the presence of organic impurities in the coal-pyrite used in our experiments.

The analytical technique similar to that used to follow the concentration of dextrin[9,10] was tested for carboxymethyl cellulose in our lab. Unfortunately, it cannot be used if other substances, like humic acid, are present in the system. Comparison of the effect of the studied modifiers on the surface properties and floatability of various solids involved could then be based only on the direct flotation and zeta potential measurements.

BENCH SCALE FLOTATION OF THE LOW-SULPHUR BITUMINOUS AND HIGH-SULPHUR DEVCO COALS

Since humic acid was found to strongly affect the surface properties and floatability of graphite and coal[4,8] we have further tested the use of this agent in the flotation of various coals. Figure 31 details the experimental procedure in the first series of bench flotation experiments. In the standard batch flotation tests, 900 g/t kerosene emulsified with 50 g/t MIBC was added, followed by another 50 g/t MIBC introduced directly to the flotation machine in the form of 1 g/l aqueous solution. In the next experiments 2.5 kg/t humic acid was added first, and after conditioning it with the pulp for one minute, a 900 g/t emulsified kerosene and 100 g/t MIBC was introduced. As shown in Figure 32 (Table 6), the flotation is depressed when kerosene is added one minute after humic acid. Addition of another 300 g/t of emulsified kerosene with 100 g/t MIGC after one minute of flotation in the third experiment did not increase the yield significantly, but it substantially reduced ash content in the froth product. This trend has been observed in all subsequent experiments. The greater the time which elapses after the first addition of humic acid, the more drastic is the increase in the concentrate yield. Increase in the yield is not, however, accompanied by an increase in the ash content which indicates that flotation is much more selective under such conditions.

Gulf fuel oils seem to be much more active flotation collectors than kerosene. Improved selectivity is observed if an additional amount of the oil is added shortly after humic acid (Figure 33, Table 7). If the subsequent portion of the oil is introduced 4 or more minutes after humic acid then very intense flotation is again restored, however, this is accompanied by an increase in ash content of the concentrate.

Figures 34 and 35 (Tables 8 and 9) illustrate results obtained with a -500μm DEVCO coal. In this case selectivity does not seem to be very different from the experiments without humic acid. This controversy has, however, been clarified when DEVCO -200μm and DEVCO -75μm coal samples were used in the flotation tests (Figures 36, 37 and 38 (Tables 10 through 12)).

Results obtained with finer ground feeds clearly follow the trend observed in the experiments with Fording coal. This may indicate that poor liberation was responsible for slightly different results with a -500μm DEVCO coal. It is to be noted that total sulphur content is almost 4% for the -75μm DEVCO coal concentrate floated with 900 g/t kerosene and 100 g/t MIBC, while the concentrate obtained from the same feed but floated with humic acid and kerosene may content below 3% of total sulphur.

Selectivity of the flotation with the use of humic acid, kerosene and MIBC clearly depends on the time of conditioning with humic acid, as shown in Figures 32 to 38. To further examine this phenomenon additional flotation experiments have been carried out with DEVCO -500 and -200μm coal samples according to the procedure depicted in Figure 39. The results of these experiments are given in Figures 40 and 41 (Tables 13 and 14). Very similar results have been obtained in the tests with DEVCO -500μm sample. As seen, even six minutes conditioning with humic acid before the addition of kerosene does not improve flotation which is still strongly depressed. It is then not the abstraction of humic acid from the pulp that reduces its depressing ability with time of conditioning. The beneficial time effects are observed only when humic acid and kerosene are conditioned together with the pulp for a few minutes. The process seems to be similar to an agglomerate flotation which involves conditioning of a pulp at high solid/liquid ratio

with a collector and then with an apolar oil. The conditioning with oil leads first to non-selective wetting and agglomeration of all particles, but with the increased time of conditioning selective redistribution of oil on the surface of solid particles intensified by attrition, takes place and this finally provides good selectivity.[11] Similar phenomena seem to be involved in the flotation of coal with humic acid and kerosene. After conditioning both reagents with coal for a few minutes, subsequent smaller additions of kerosene leads to much more selective flotation. The effect caused by the second addition of emulsified kerosene is clearly related to the time of conditioning of the humic acid and kerosene with coal. In our experiments the best results have been obtained after 4 mins. conditioning.

The use of carboxymethyl cellulose in fine coal processing may be very beneficial[12,13]. As shown in the second section, CMC may depress floatability of coal in the acidic media, but its use in an alkaline pH may even improve floatability. Our results obtained with MIBC, with and without CMC (low and high molecular weight samples of CMC were used) in the experiments with a -75μm DEVCO coal confirmed previous observations (Figure 42, Table 15). Yield of concentrate is not affected by the presence of CMC in the flotation with 400 g/t MIBC, but ash content drops drastically from 8 to 5 percent, and total sulphur content is reduced by almost 1% (from 3.5 to 2.8%). These beneficial effects were observed especially in the experiments carried out under alkaline conditions. Figure 43 (Table 16) illustrates this trend. It also shows that comparable results may be obtained with humic acid.

Figure 44 (Table 17) provides the results obtained with dry and wet ground -75μm DEVCO coal and humic acid. Dry ground feed was floated with the same reagents as in the experiments illustrated in Figure 38, but coal was blended in a coffee mixer with the reagents (2.5 kg/t humic acid + 900 g/t kerosene emulsified with 100 g/t MIBC) for 10 minutes, then transferred to a flotation cell and floated after adding another 300 g/t kerosene and 100 g/t MIBC. In the course of flotation, 100 g/t MIBC more was applied. The results are slightly better than those given in Figure 38. Wet grinding of coal with 2.5 kg/t humic acid and emulsified 900 g/t emulsified kerosene with 200 g/t MIBC and two more additions of 200 g/t MIBC also produced promising results.

CONCLUSIONS

1. Total sulphur determined from the Eschka method has been utilized as a measure of selectivity in our flotation tests. It seems that pyritic sulphur content may be a more useful indication of selectivity if the work is continued.

2. Our preliminary results on the effect of feed top size on DEVCO coal pyrite liberation show that significant liberation of pyrite takes place only when the top size is reduced below 200μm. Grinding below 75μm will be required in all future experiments and the effect of the dry and wet grinding on pyrite liberation should also be studied.

3. Our small scale flotation experiments indicate that humic acid and CMC produce strong depression of coal floated with MIBC, only when added to the pulp before the MIBC. Dextrin depresses coal floatability irrespective of the reagents addition order. In the flotation with kerosene, humic acid and dextrin depress coal flotation irrespective of the mode of reagent addition. CMC does not produce any significant depression of coal floatability when kerosene is used.

4. The use of dextrin in a two-stage reverse flotation of DEVCO -75μm coal was not successful.

5. Our measurements revealed that the zeta potential of coal and pyrite particles as well as oily collector droplets is much more negative in the presence of humic acid and carboxymethyl cellulose. While the contribution of the increased negative electrical charge to overall wettability of hydrophobic coal particles is probably not significant, it seems to appreciably increase the hydrophilicity of pyrite and other gangue particles.

6. Our zeta potential and floatability studies revealed that the mechanism of action of the examined modifiers (humic acid, carboxymethyl cellulose, dextrin) can be very different. While the electrical effects seem to determine the behaviour of humic acid, dextrin does not affect either the zeta potential of coal particles or the zeta potential of oily collector droplets and its influence on the flotation does not depend on the pH at all. Carboxymethyl cellulose behaviour in the coal flotation system is strongly dependent on the pH and this reagent may even enhance coal floatability while depressing gangue under alkaline conditions.

7. Flotation selectivity with the use of humic acid, kerosenr (or fuel oil) and MIBC has been shown to depend strongly on the time of conditioning with humic acid and kerosene (or fuel oil). After conditioning both reagents with coal for a few minutes, subsequent smaller additions of kerosene (or fuel oil) lead to improved selectivity. Selectivity of humic acid may be much improved through such beneficial time effects.

8. The use of humic acid and carboxymethyl cellulose in the flotation of finely ground DEVCO coal should be further studied.

REFERENCES

1. W. W. Wen and S.C. Sun, Separation Science, 16, 1491 (1981).

2. J. Leja, K. C. Teo and S. Finora, Fuel, 61, 71 (1982)

3. B. Yarar and J. Leja, Correlation of Zeta-potential and Floatability of Weathered Coal, 9th Intern. Coal Preparation Congress, New Delhi, 1982

4. K. Wong and J. Laskowski, Colloids and Surfaces. In press.

5. A. C. Partridge and G. W. Smith, Trans. IMM, Sect. C, 80, C199 (1971)

6. V. I. Klassen, Coal Flotation, Moscow 1962 (Russian text)

7. J. D. Miller, C. L. Lin and S.S. Chang, Coal Preparation International Journal, 1, 1984. In press.

8. J. Laskowski, Effect of Humic Acid on Floatability of Coal and Pyrite, DSS Contract OSV82-00042, 1983

9. J. M. Wie and D. W. Fuerstenau, Int. J. Mineral Processing, 1, 17 (1974)

10. M. Dubois, K. A. Gilles, J. K. Hamilton, P. A. Rebers and F. Smith, Analytical Chemistry, 28, 350 (1946)

11. M. Lapidot and O. Mellgren, Trans. IMM, Sec. C, 77, C149 (1968)

12. Z. Blaschke, Beneficiation of Coal Fines by Selective Flocculation, 7th Intern. Coal Preparation Congress, Sydney, 1976, paper F-2.

13. R. E. Hucko, US Bureau of Mines Report of Investigation, No. 8234, 1978

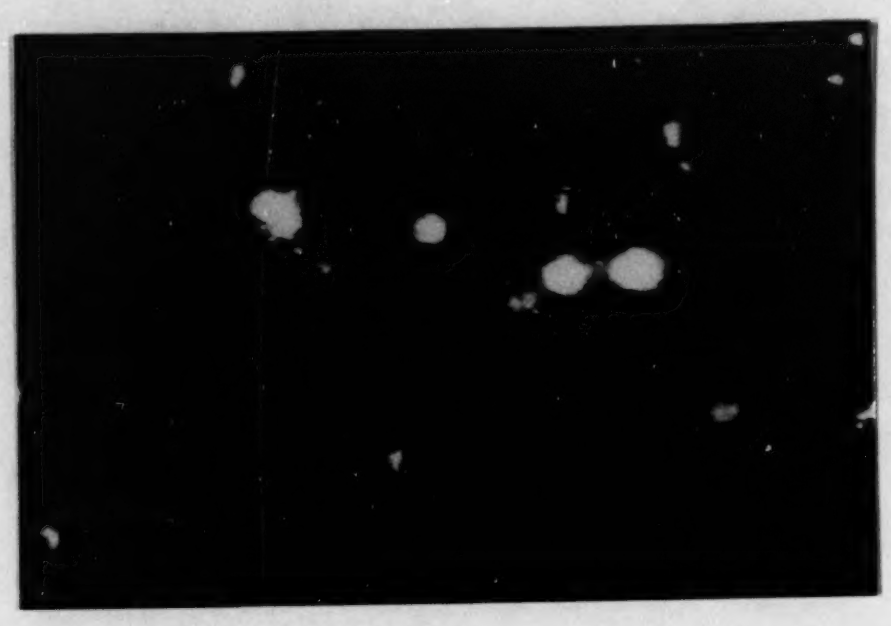


Fig. 1. Massive and fine pyrite framboids in vitrinite cell lumens (-500+425μm size fraction). x 144.

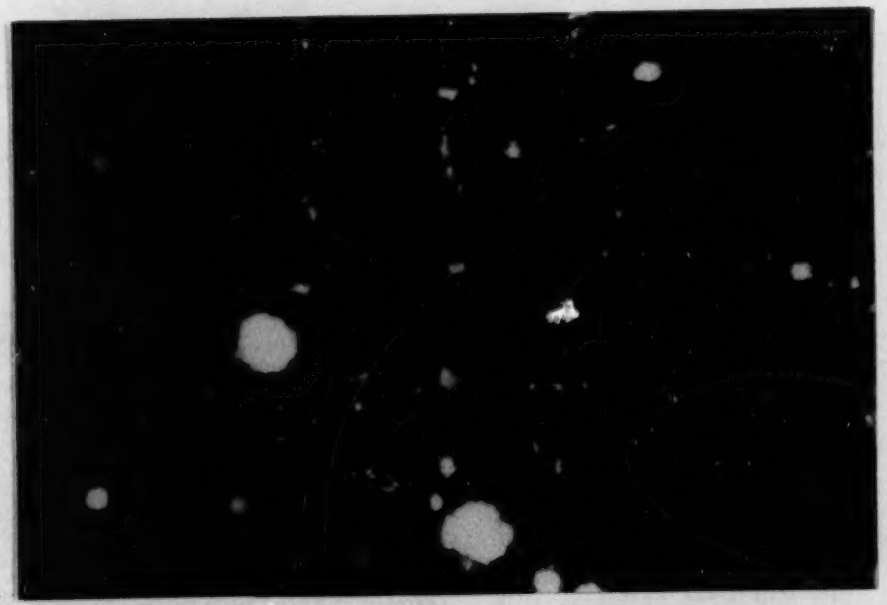


Fig. 2 Framboids clearly following along laminations in vitrinite (-425+300μm size fraction). x 200.

Fig. 3. Massive pyrite in argillite (-425 + 300µm size fraction). x 144.

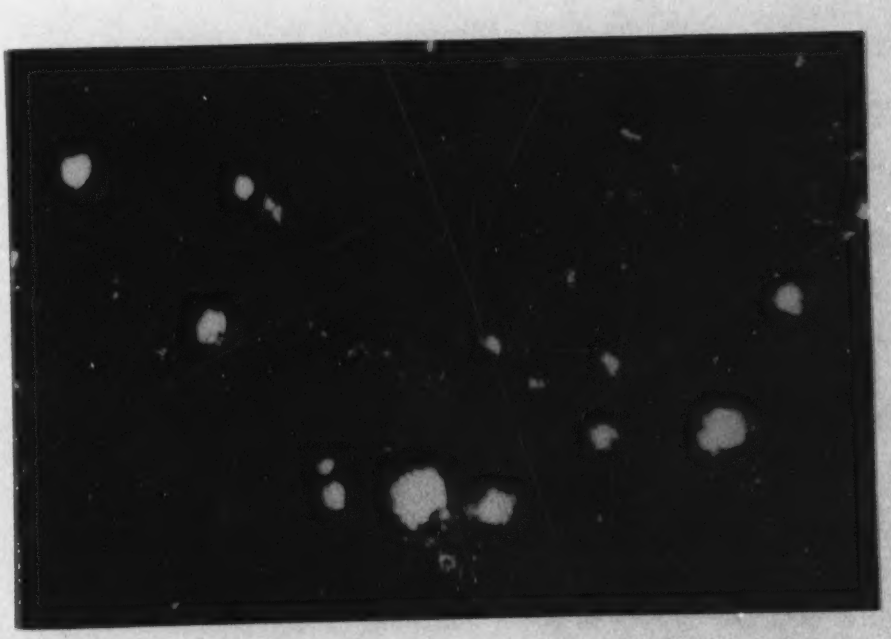


Fig. 4. Coarse framboids selectively in spores (-425 + 300µm size fraction). x 128.

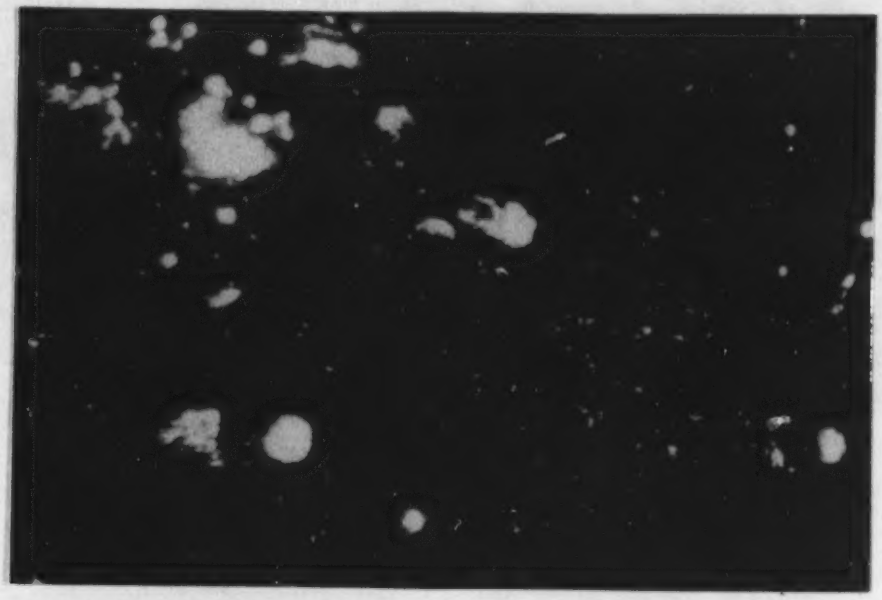


Fig. 5. Massive, framboidal and bleb forms of pyrite in vitrinite (0425+300μm size fraction). x 200.

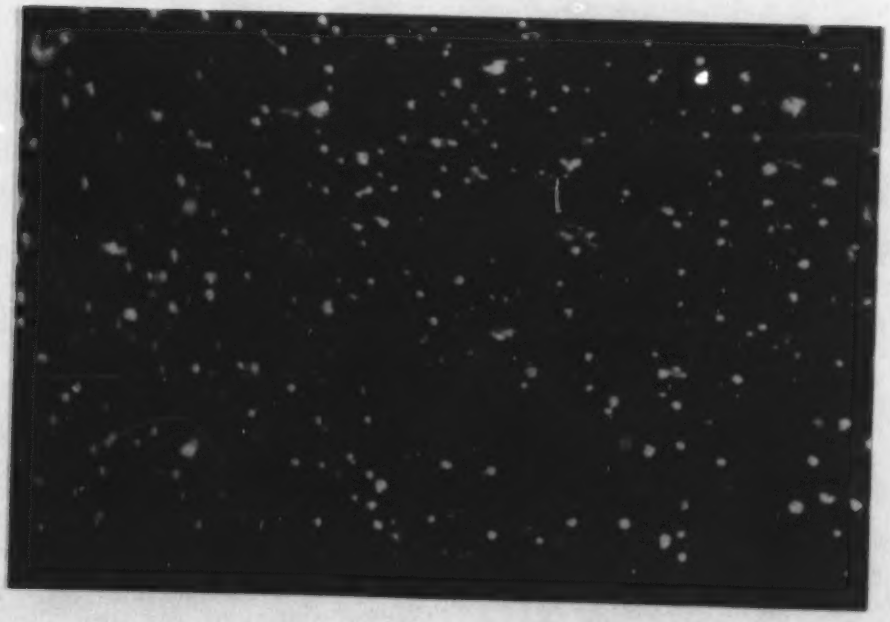


Fig. 6 Framboidal pyrite in vitrinite (-212 + 150μm size fraction). x 200.

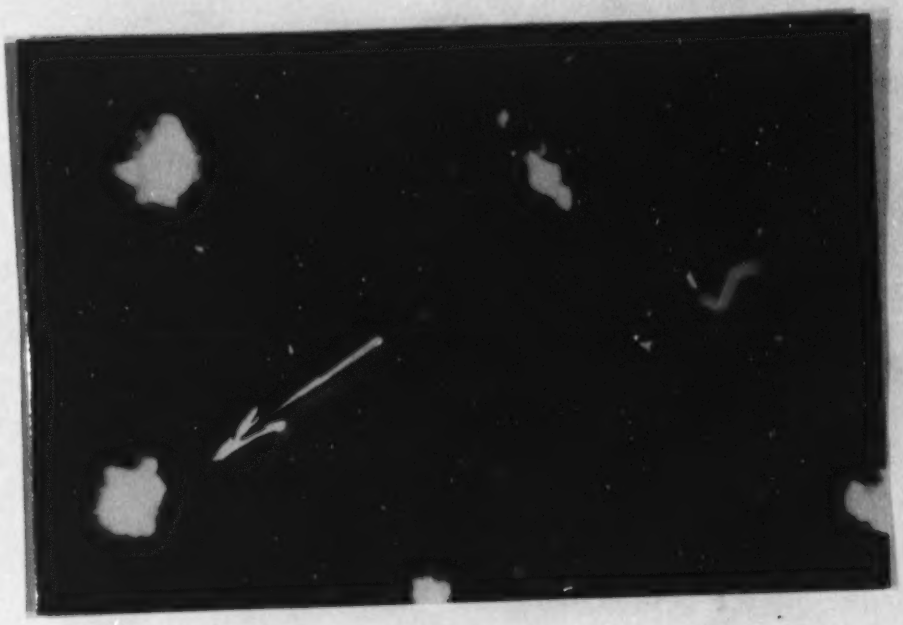


Fig. 7. Massive pyrite; note almost liberated grain at broken edge of vitrinite (-500 + 425μm size fraction). x 144.

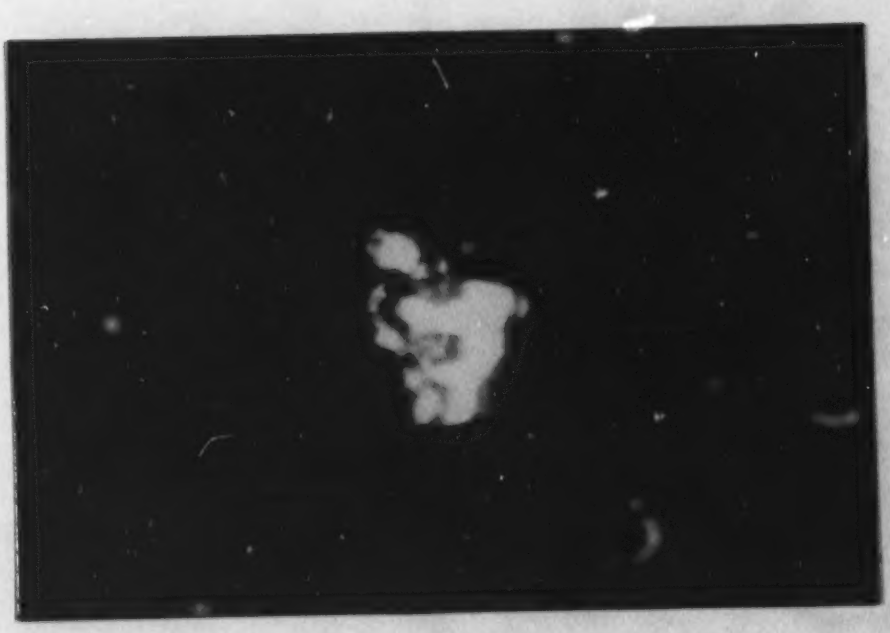


Fig. 8. Liberated pyrite grain holding some vitrinite (-425 + 300μm size fraction). x 112.

Fig. 9 Effect of Humic acid concentration on zeta potential of Kerosene droplets, pH= 4.5 - 7.9

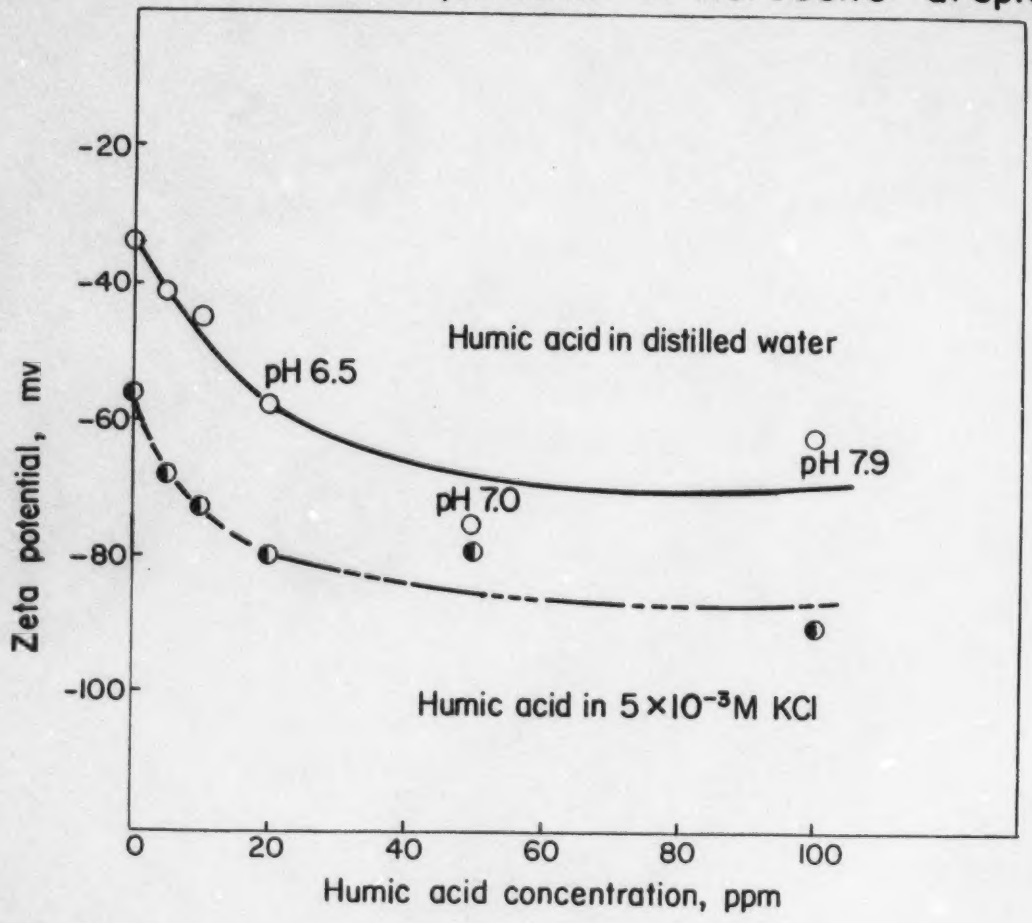


Fig. 10 Zeta potential of kerosene drops in 20 ppm depressant solutions vs. pH

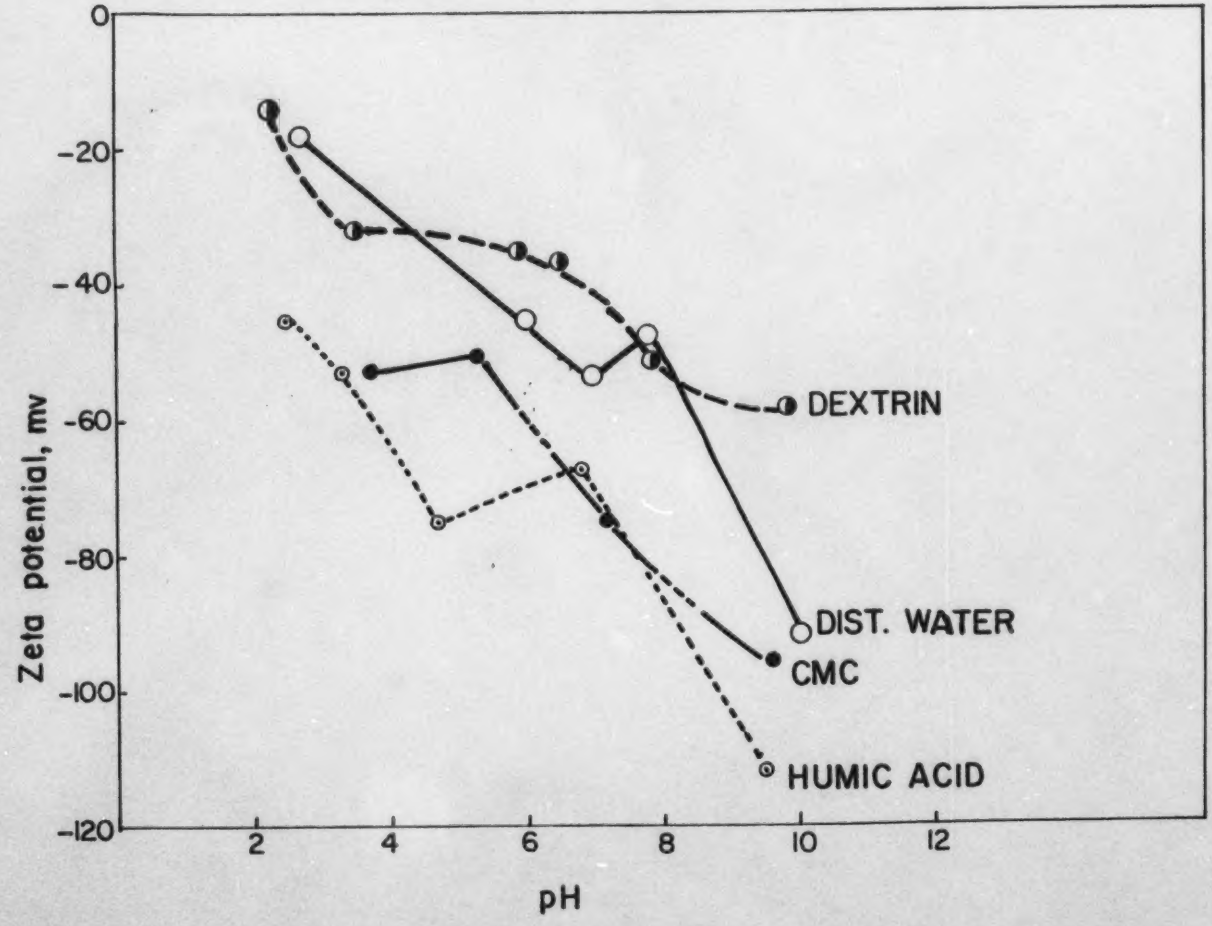
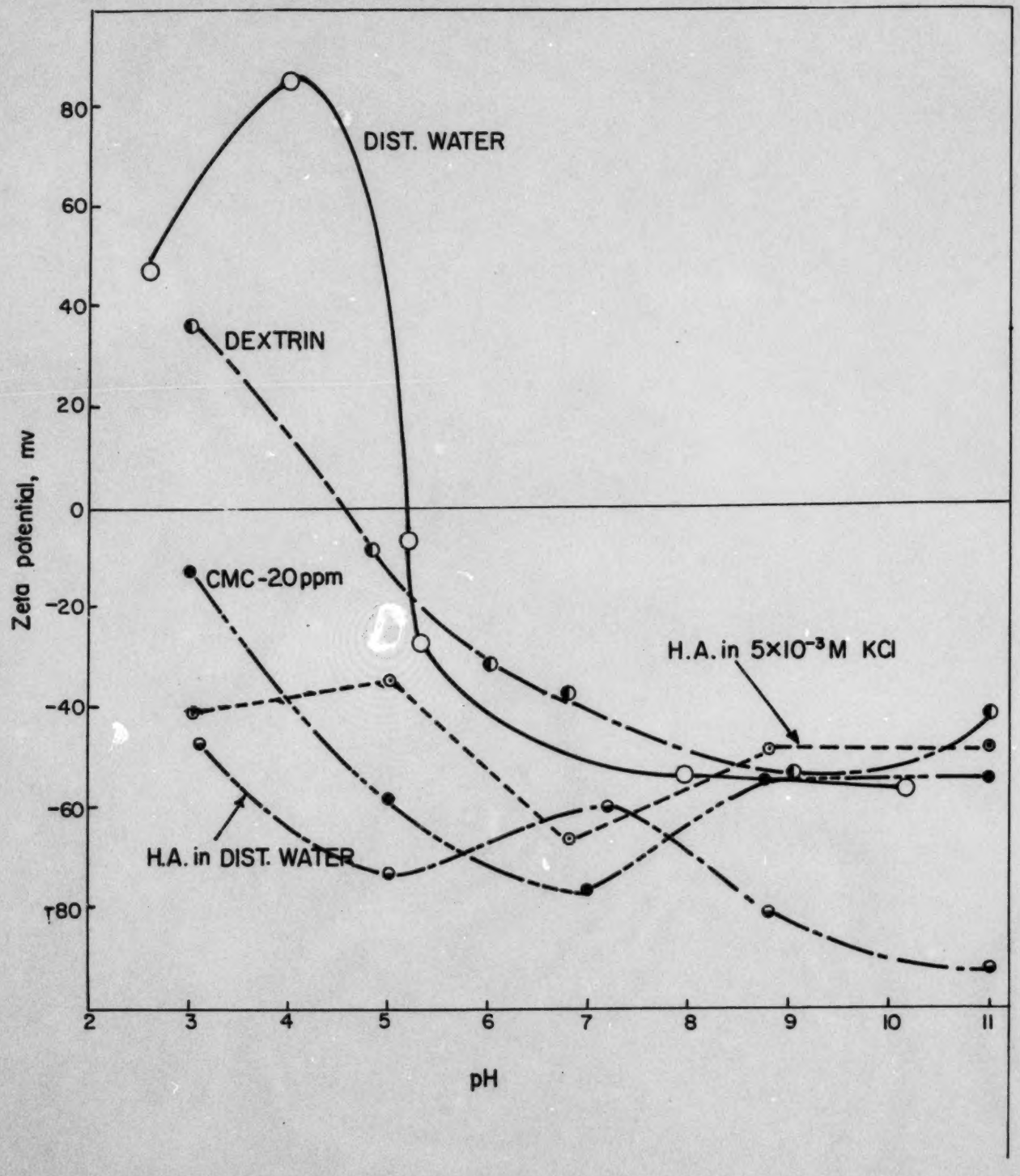


Fig. 11 Zeta potential vs. pH of 4:1 #2 and #6 oil in 100 ml. solution; 5 min. conditioning.



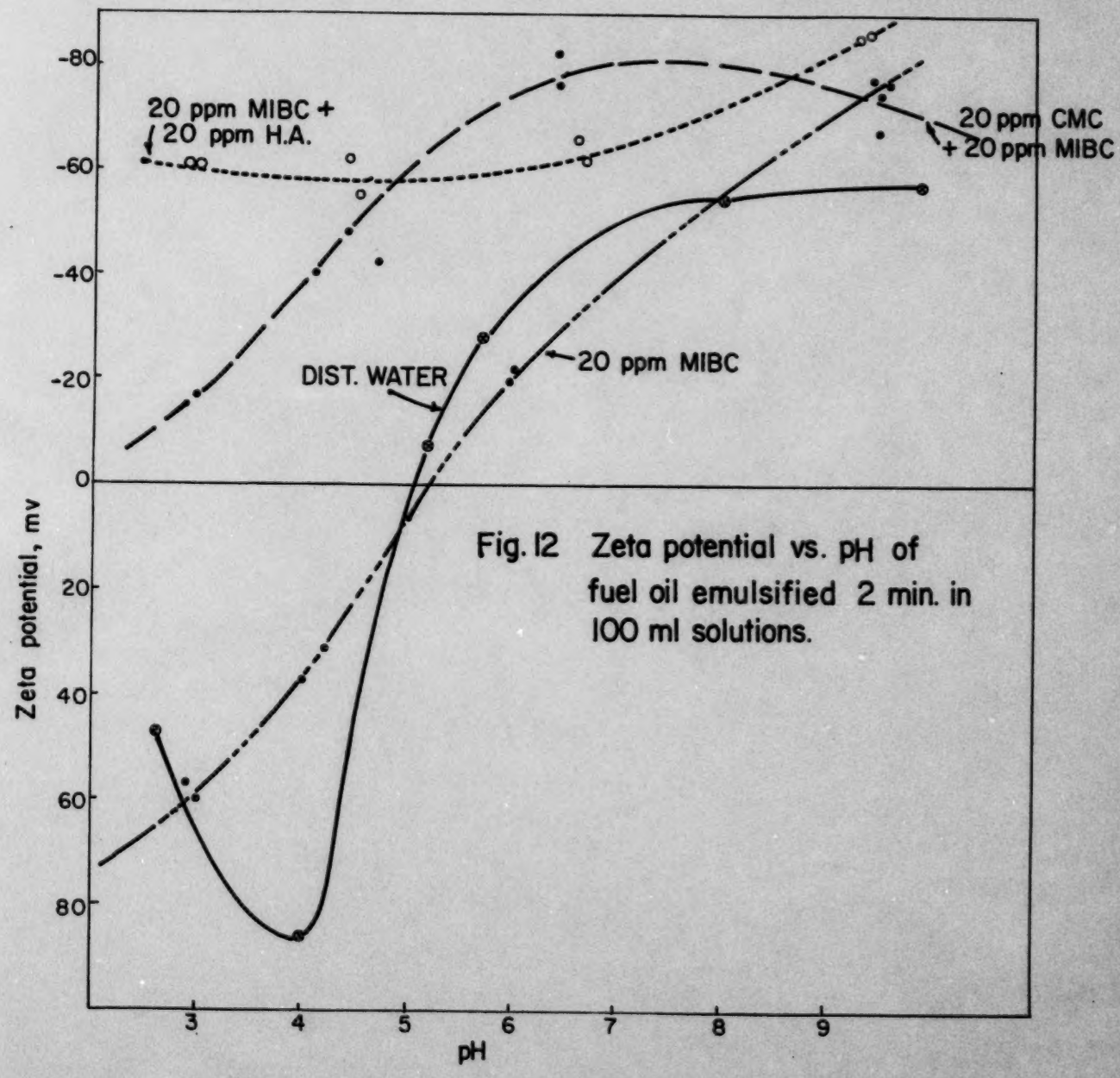


Fig. 12 Zeta potential vs. pH of fuel oil emulsified 2 min. in 100 ml solutions.

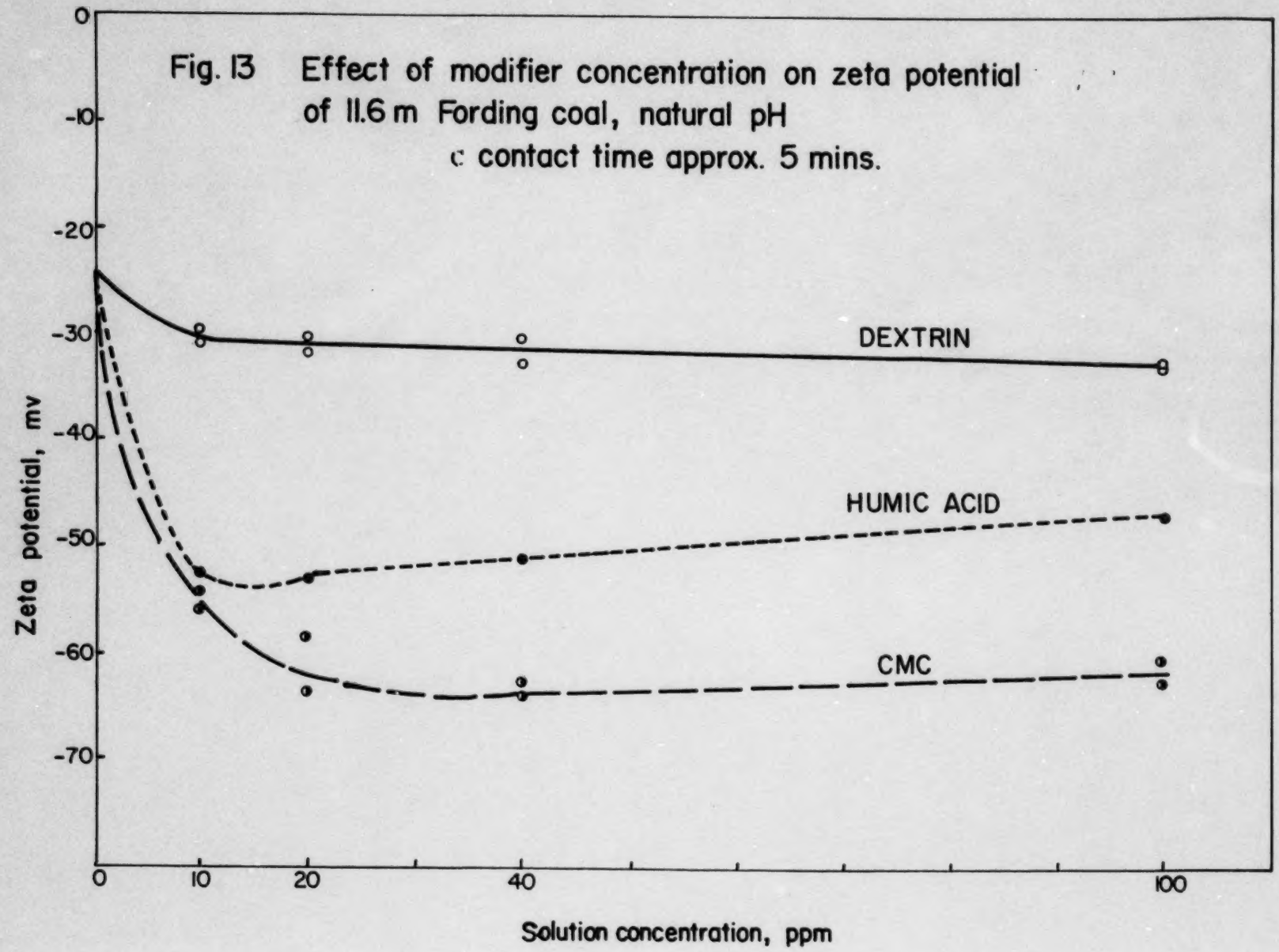


Fig. 13 Effect of modifier concentration on zeta potential of 11.6 m Fording coal, natural pH
contact time approx. 5 mins.
DEXTRIN
HUMIC ACID
CMC
Zeta potential, mv
0
-10
-20
-30
-40
-50
-60
-70
0
10
20
40
100
Solution concentration, ppm

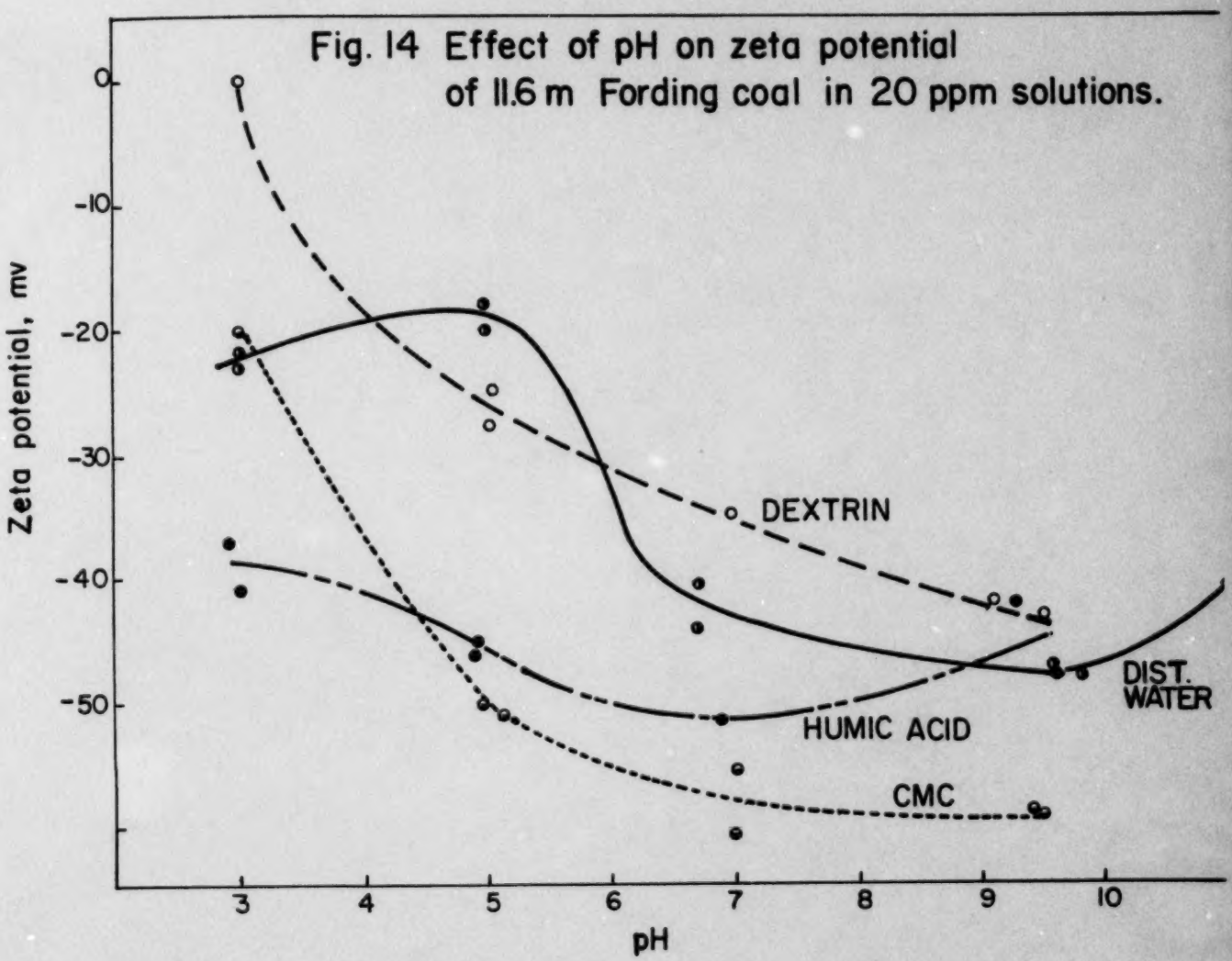


Fig. 14 Effect of pH on zeta potential of 11.6 m Fording coal in 20 ppm solutions.

Fig. 15 pH vs. zeta potential of Fording coal in 10^{-3} M KCl solutions; modifier conc. 20 ppm

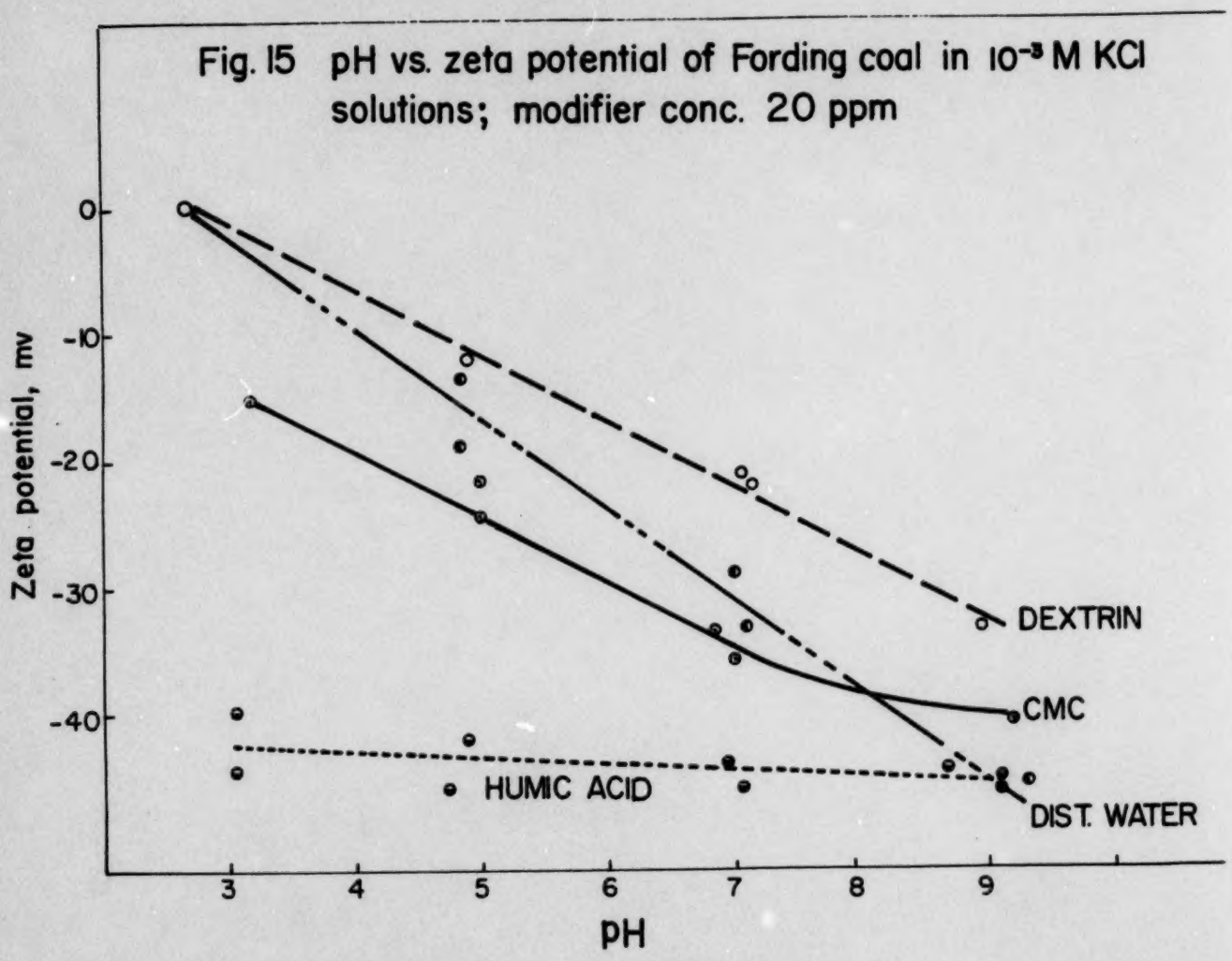


Fig. 16 Graph of % recovery of Fording coal vs. depressant concentration

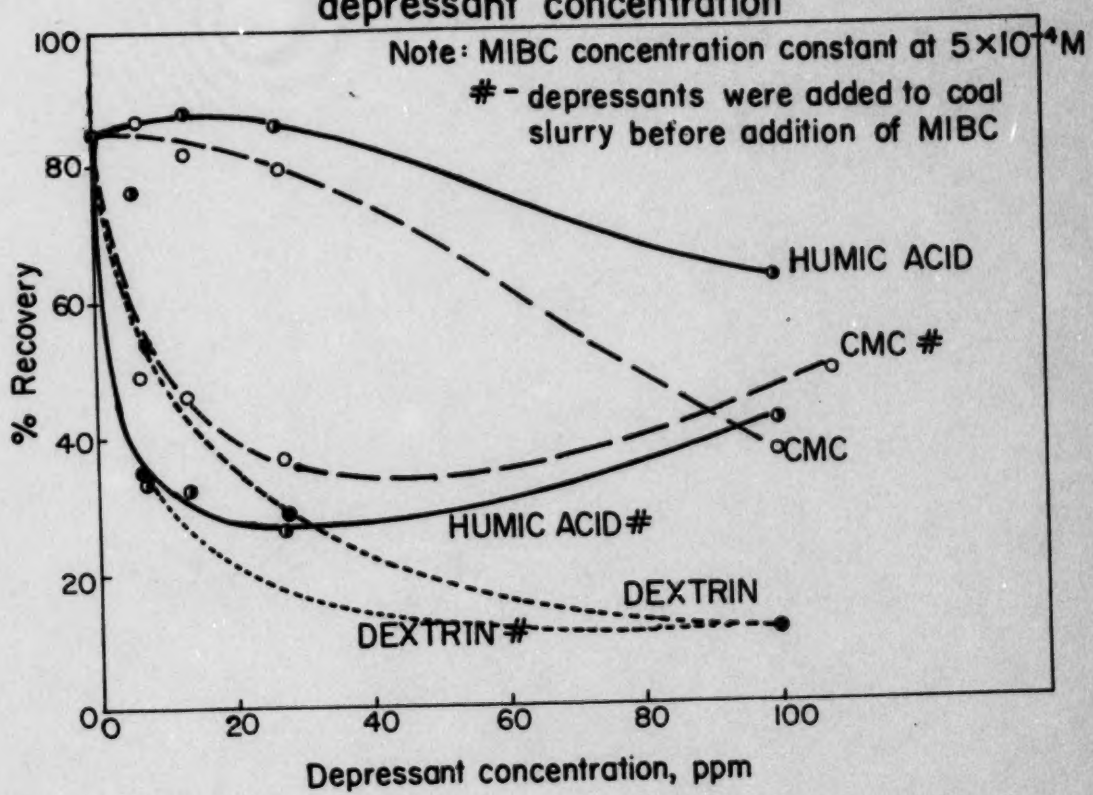


Fig.17 Graph of % recovery of Fording coal vs. concentration of CMC and Dextrin in the presence of 50ppm Humic acid and MIB(

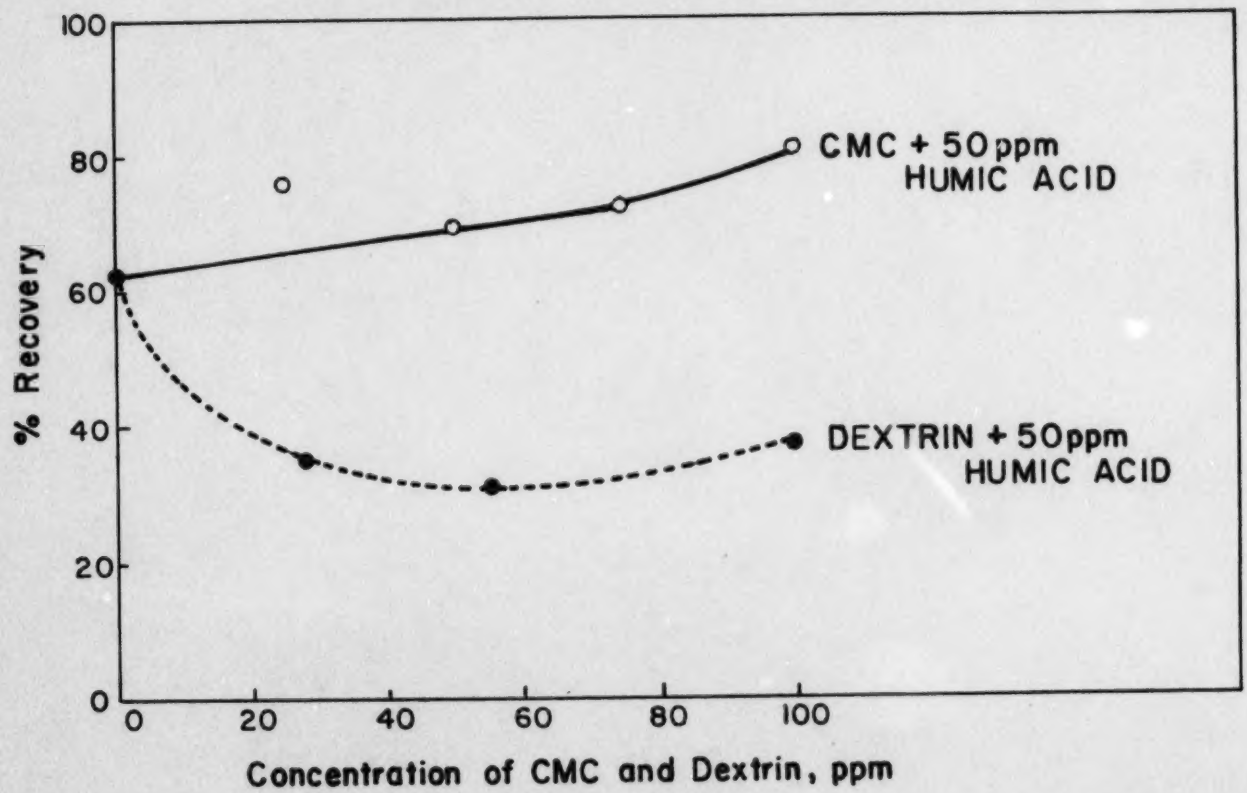


Fig. 18 Graph of % recovery of Fording coal vs. concentration of Humic acid in the presence of Kerosene

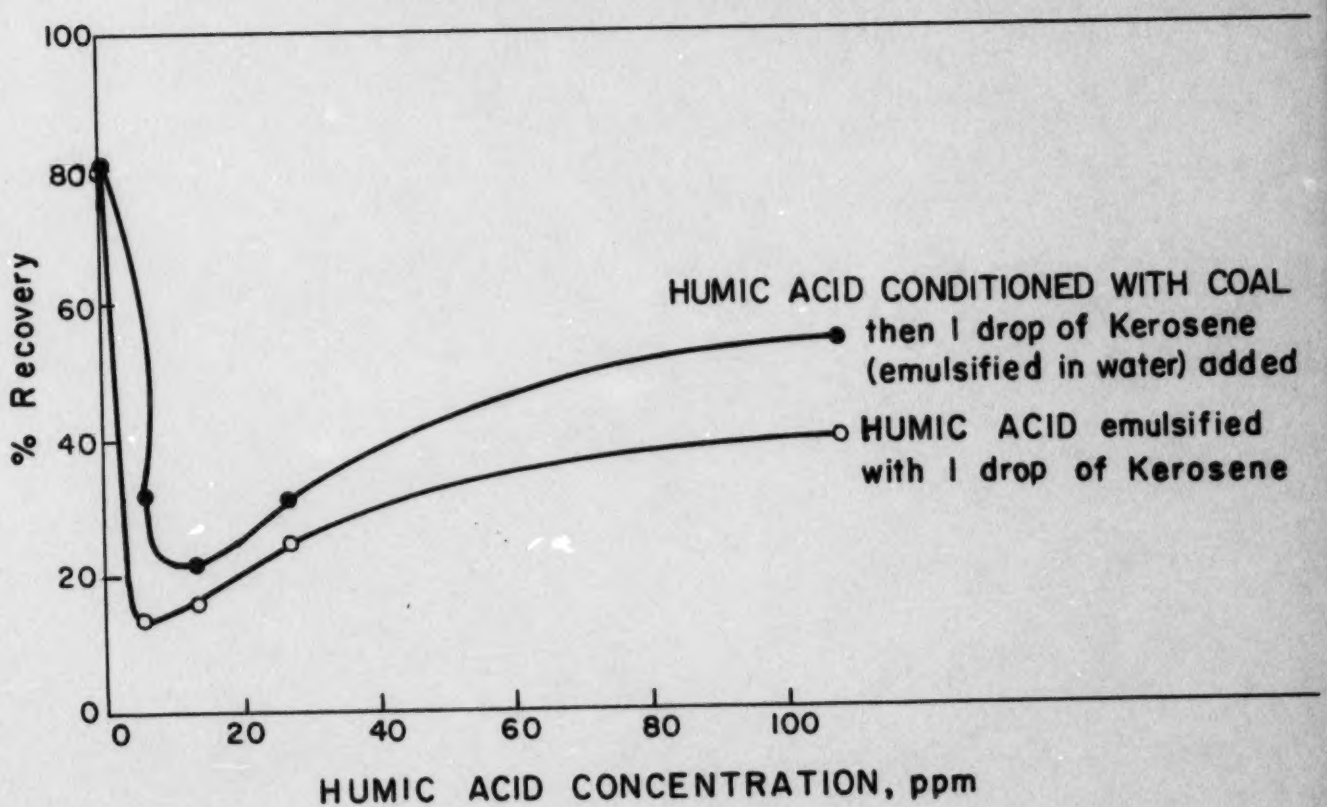


Fig. 19 Graph of % recovery of Fording coal vs. concentration of Dextrin in coal slurry in the presence of Kerosene

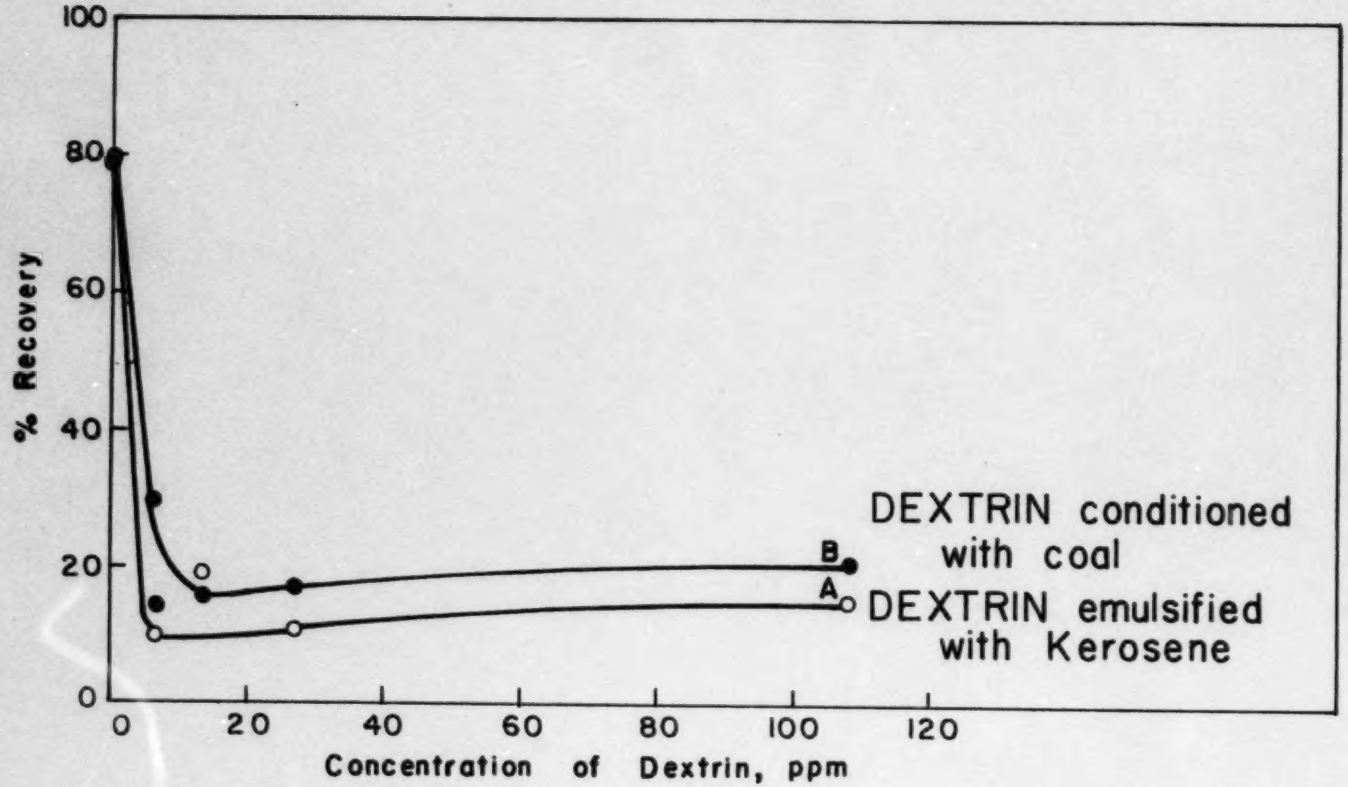


Fig. 20 Graph of % recovery of Fording coal vs concentration of CMC in coal slurry in the presence of Kerosene

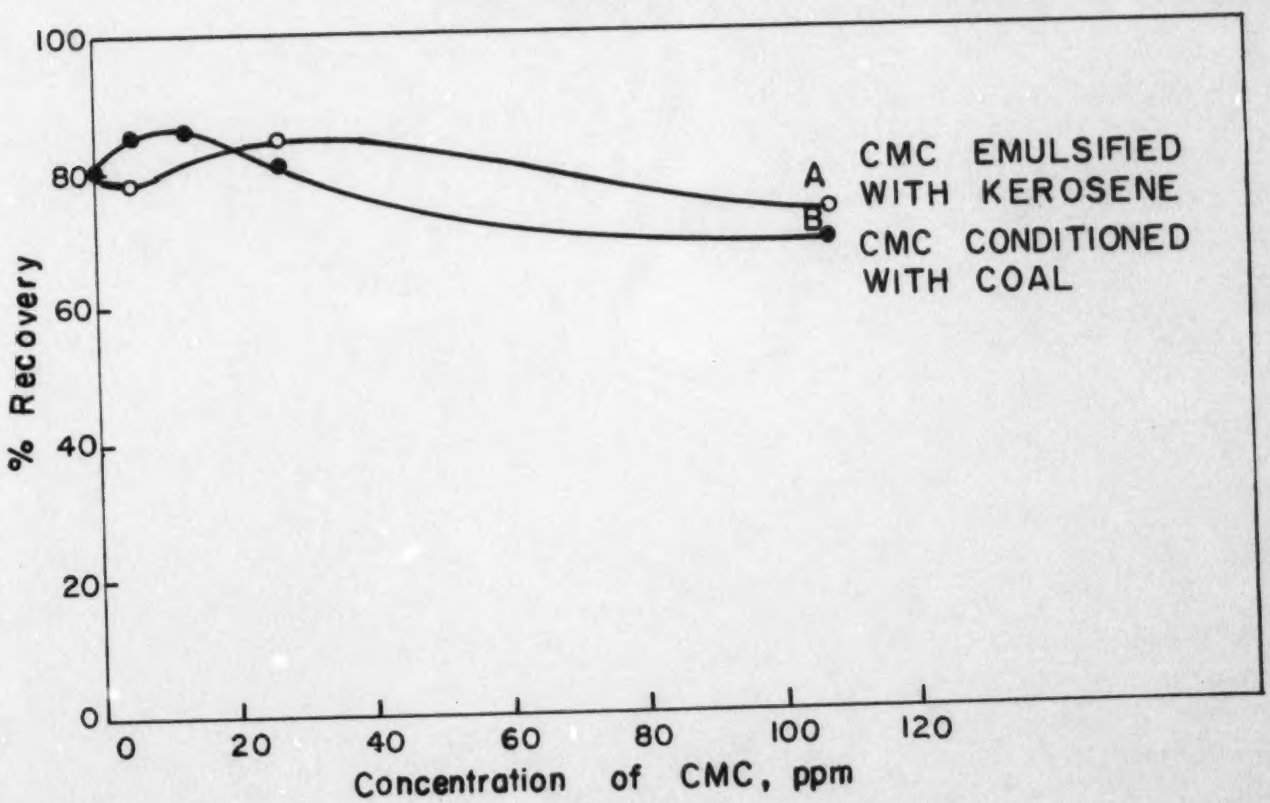


Fig. 21 % Recovery of coal vs. pH of 100 ppm depressant solutions

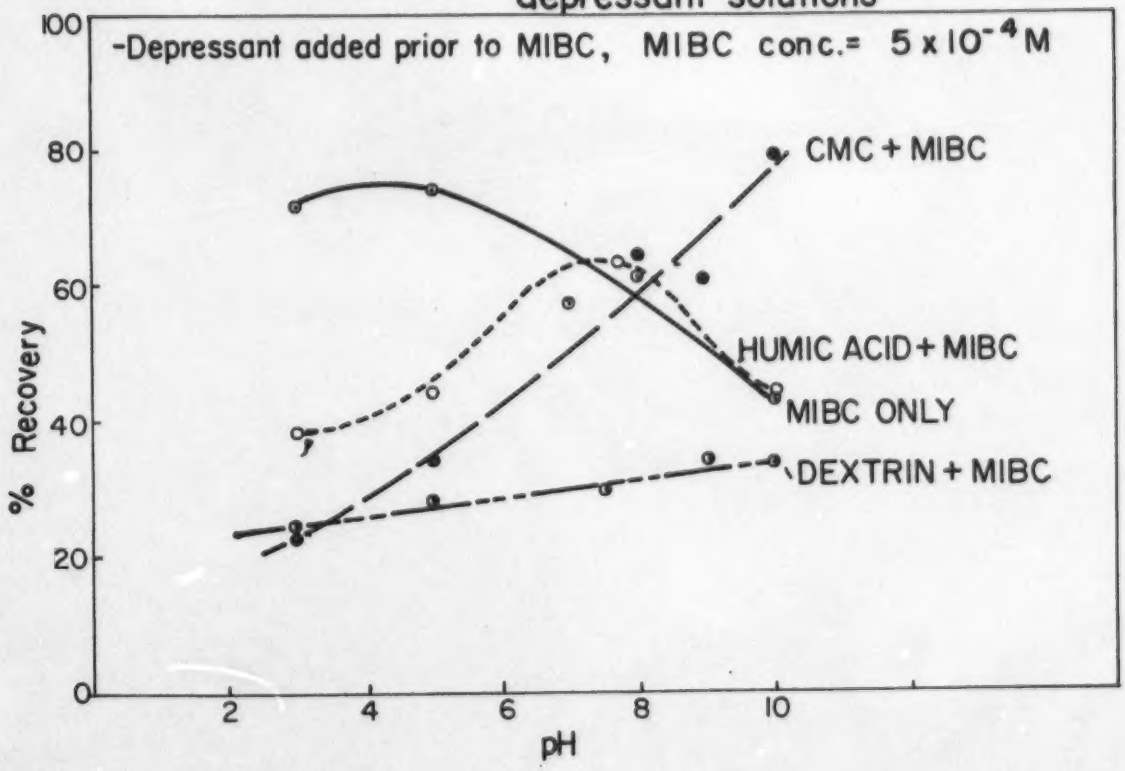


Fig. 22 Graph of % recovery of Fording coal vs. pH of 20 ppm depressant solutions in the presence of Kerosene

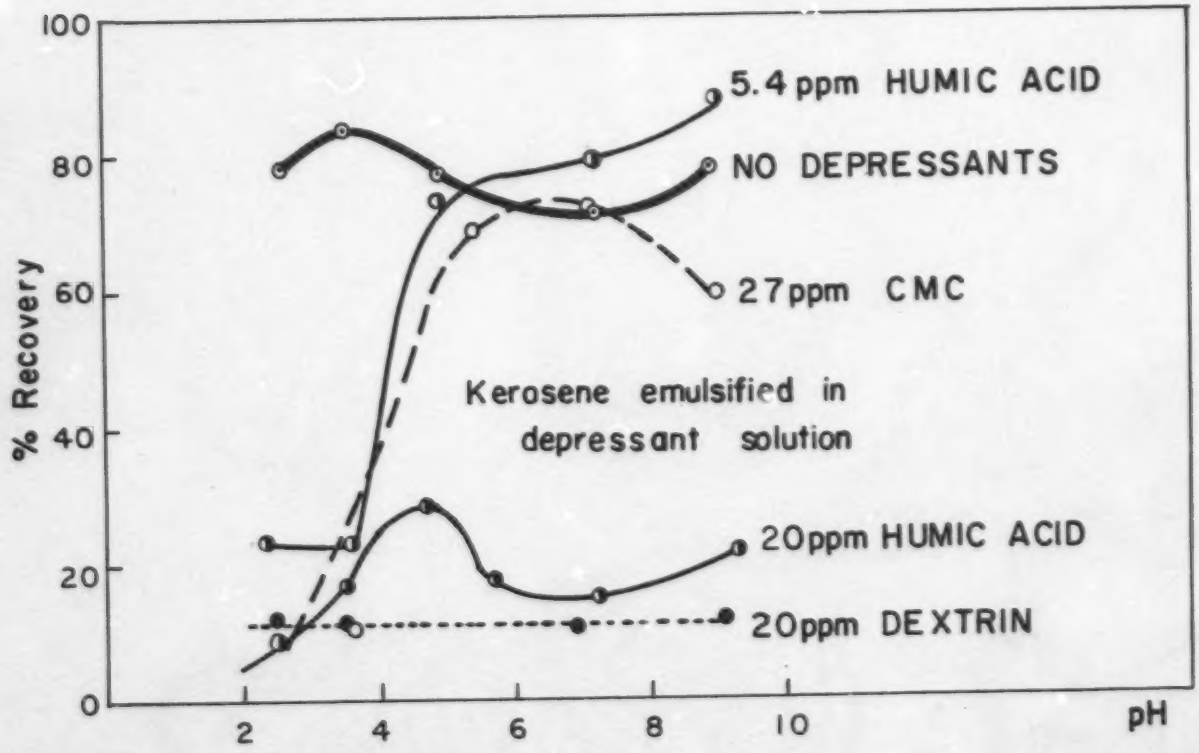


Fig. 23 Recovery of Fording coal vs. depressant concentration with Gulf fuel oil (4 parts #2 to 1 part #6)

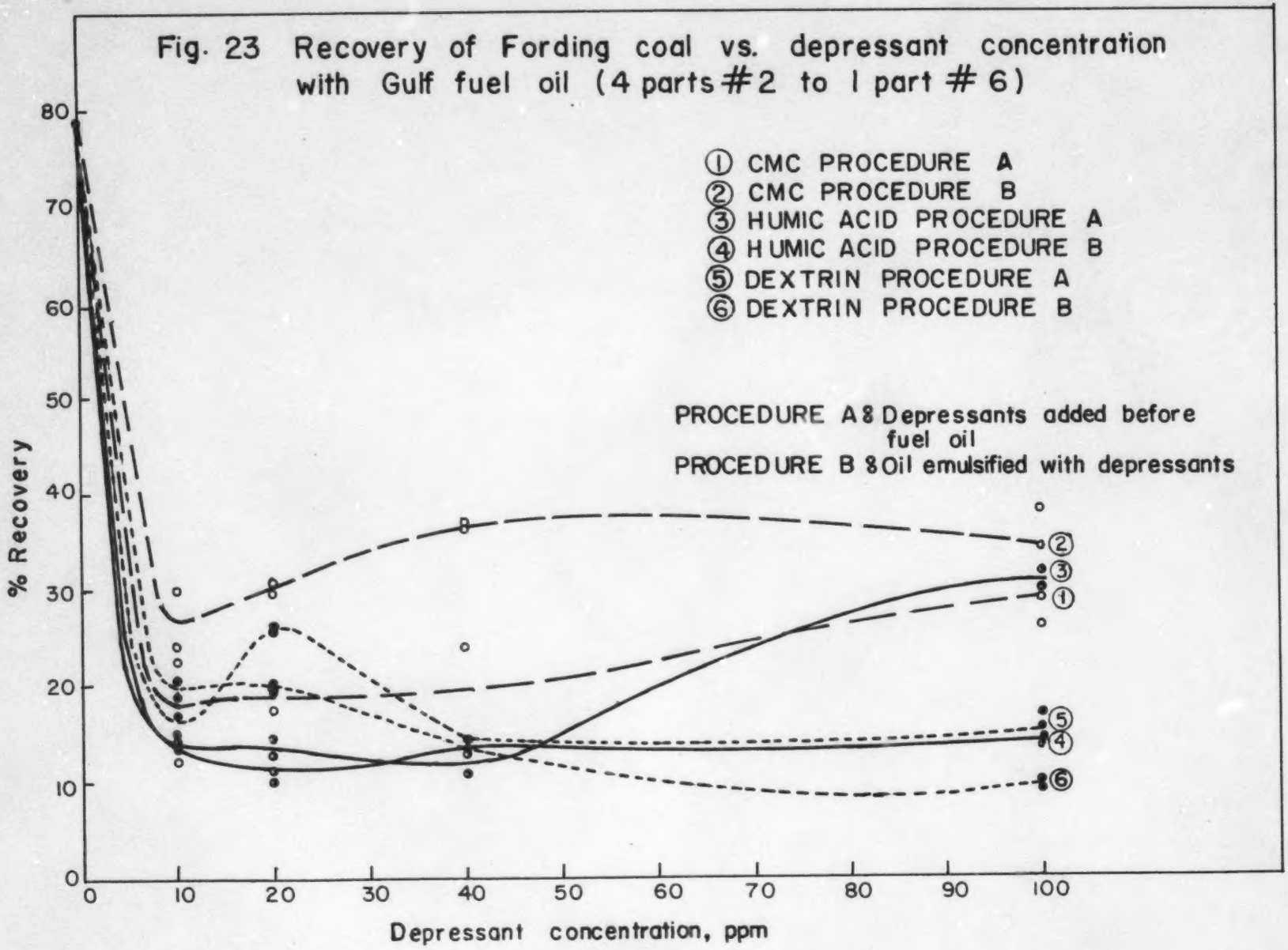


Fig. 24 Effect of pH on flotation of Fording coal with Gulf fuel oil

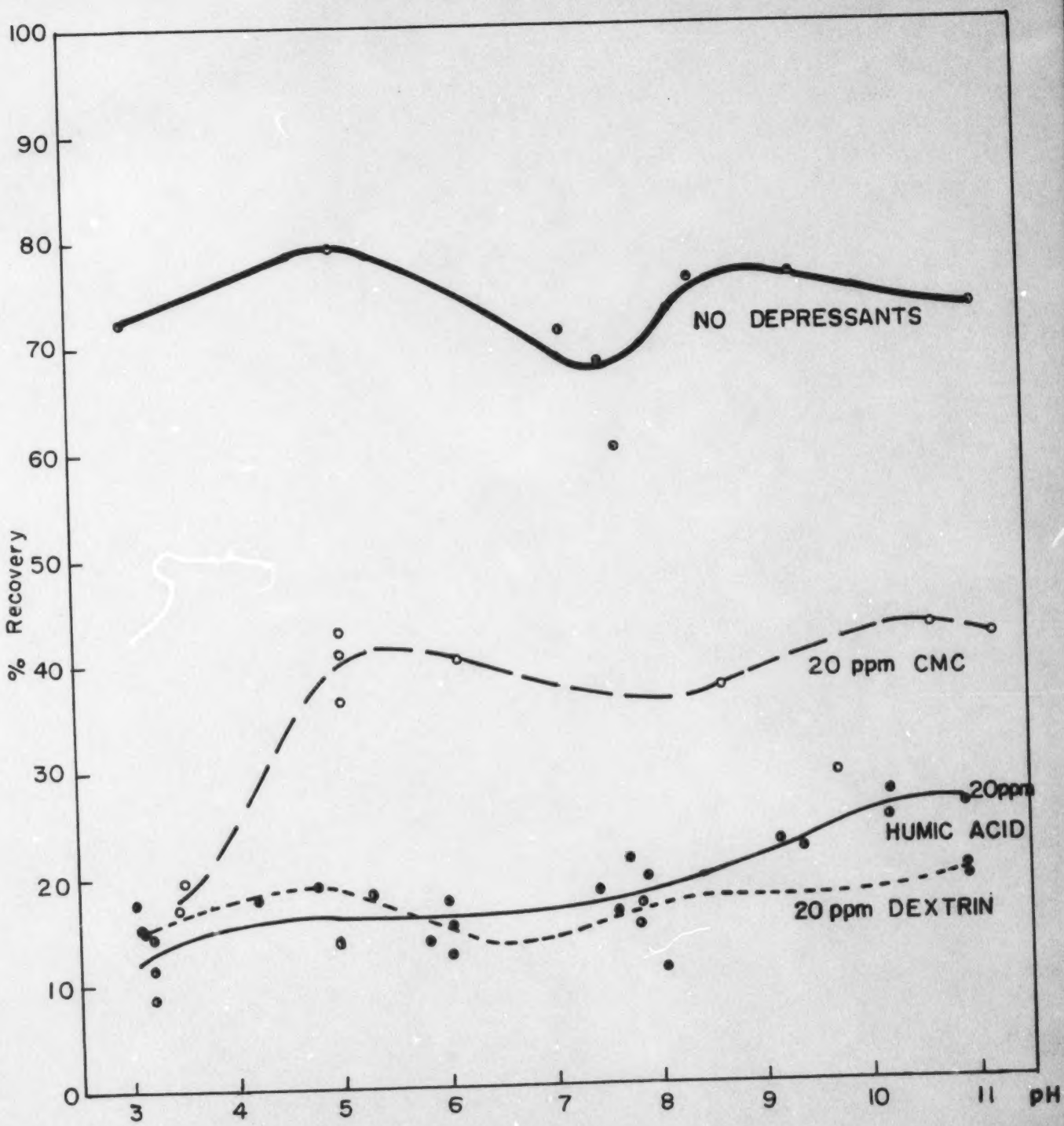


Fig. 25 Adsorption of Humic Acid on Devco coal and Coal - Pyrite vs. pH

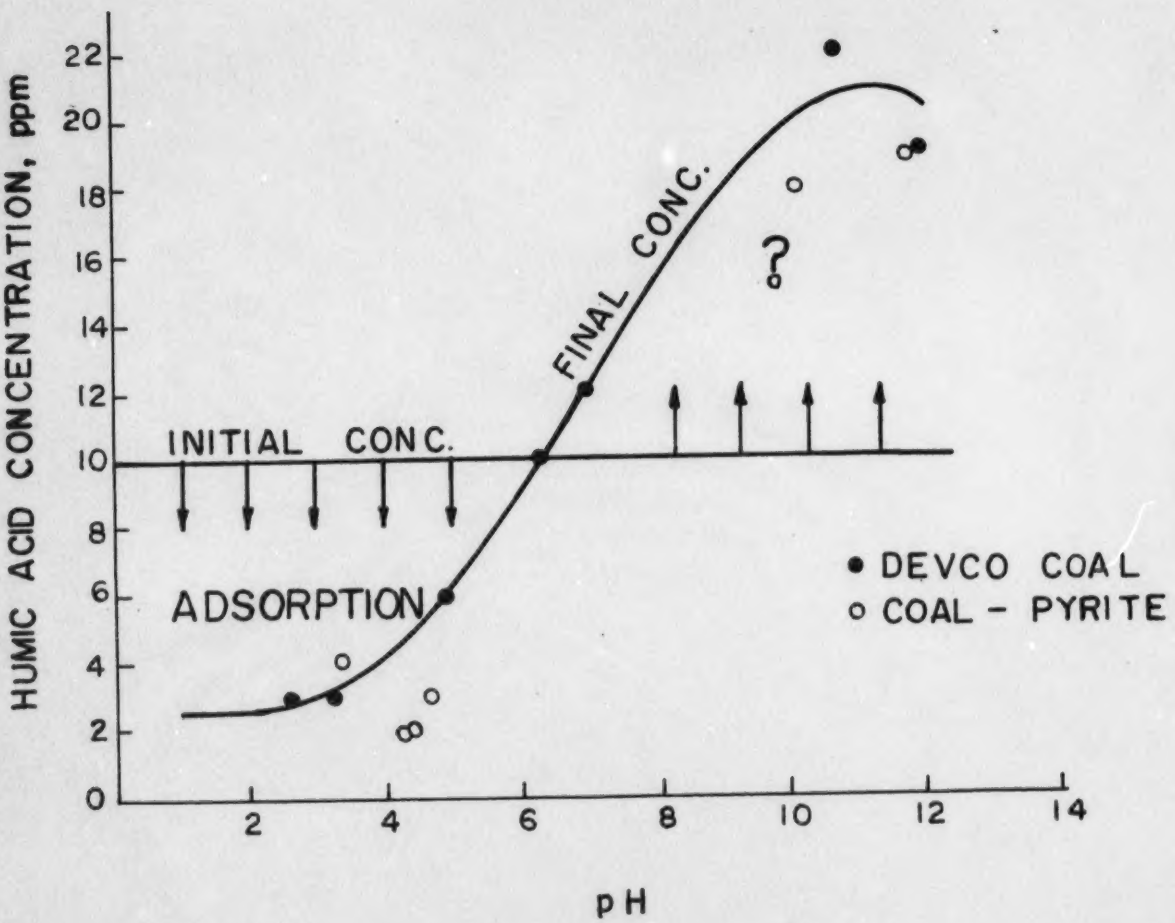


Fig. 26 Adsorption isotherm of KAmX on Devco pyrite −106 μm, pH 4.5 - 5.5

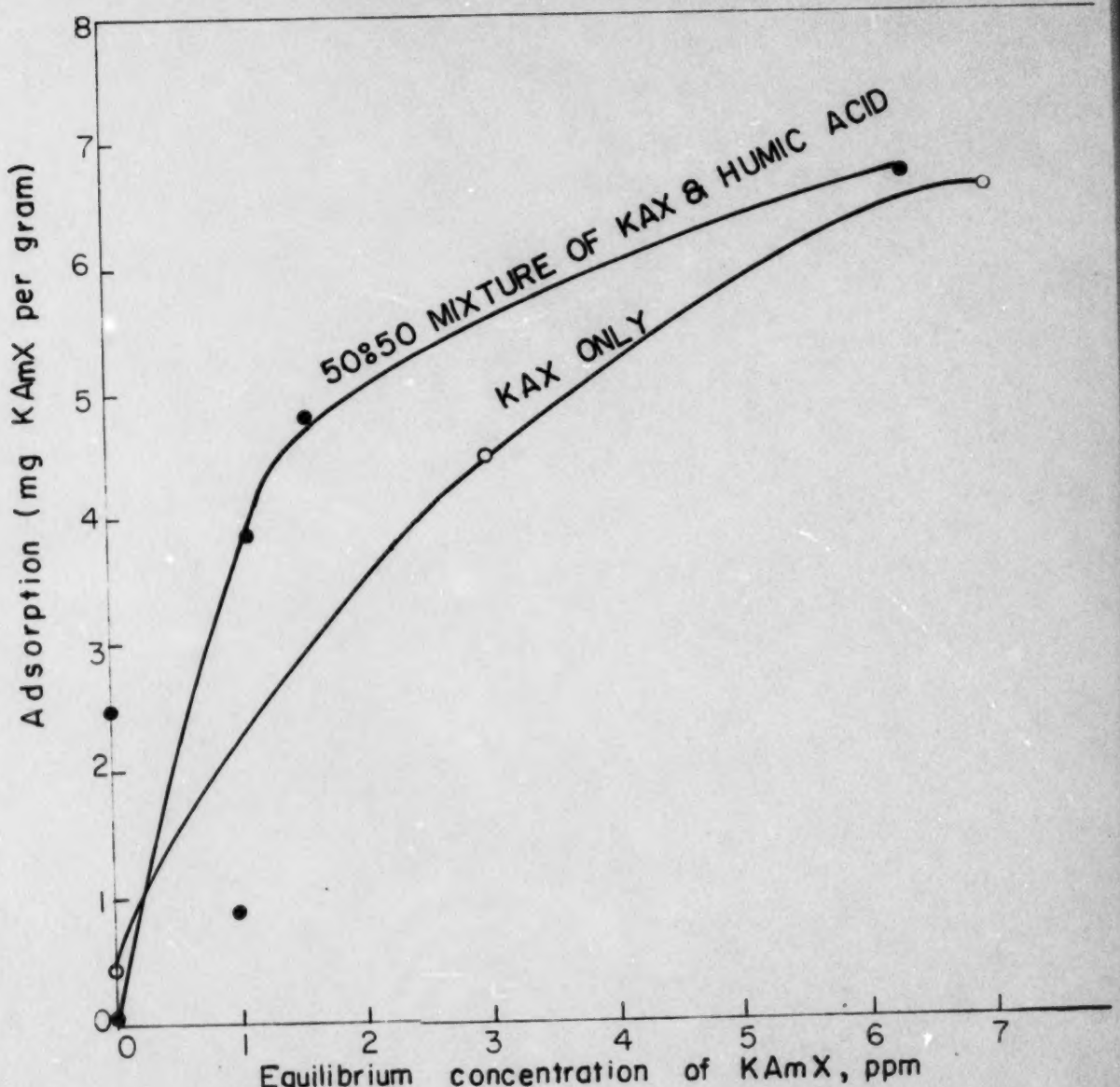


Fig. 27 Adsorption of KAX on -212 µm + 106 µm Devco Pyrite vs. pH

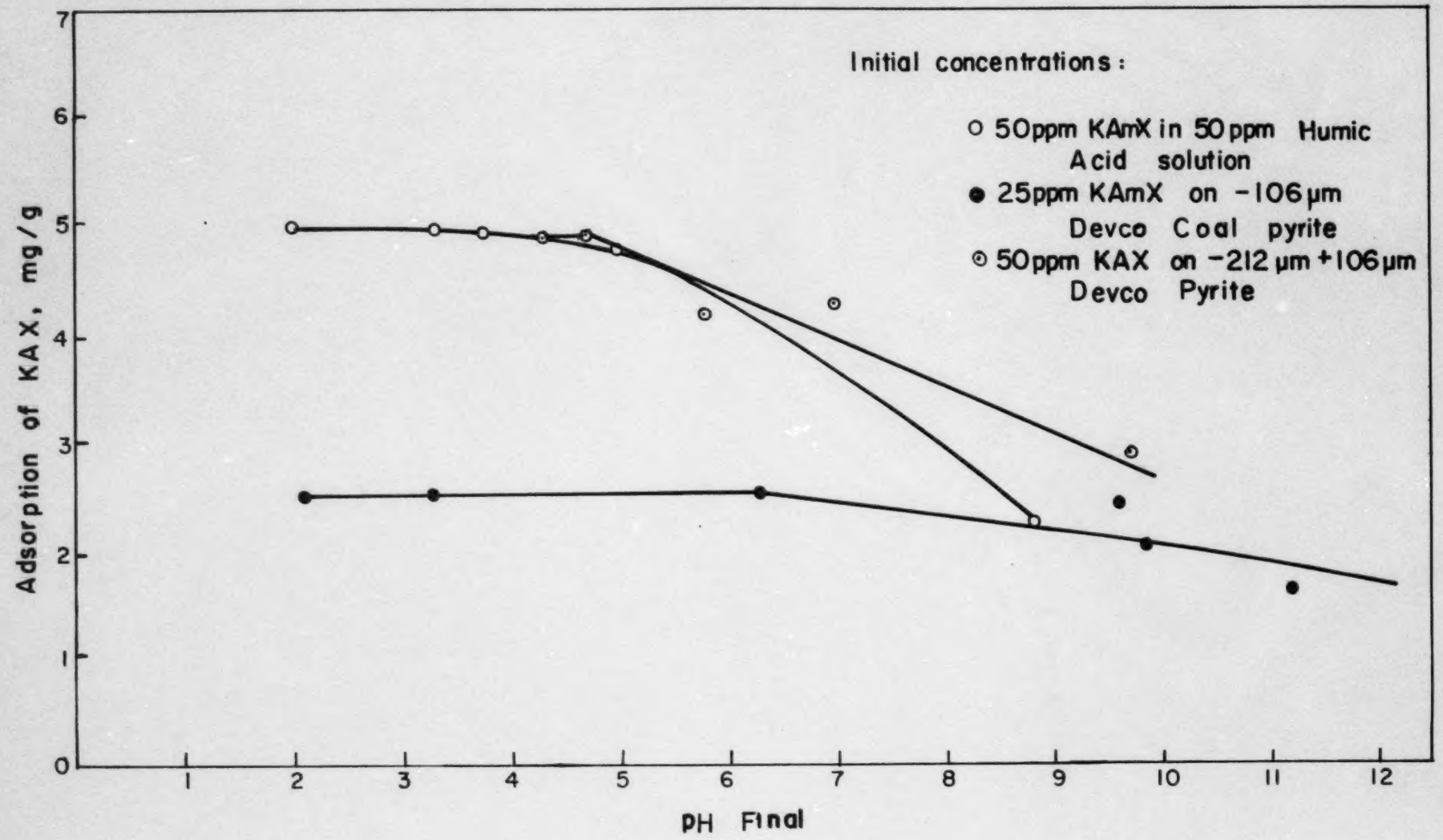


Fig. 28 Adsorption isotherm of Humic Acid on Devco Pyrite -106 µm, pH 4.2 - 5.5

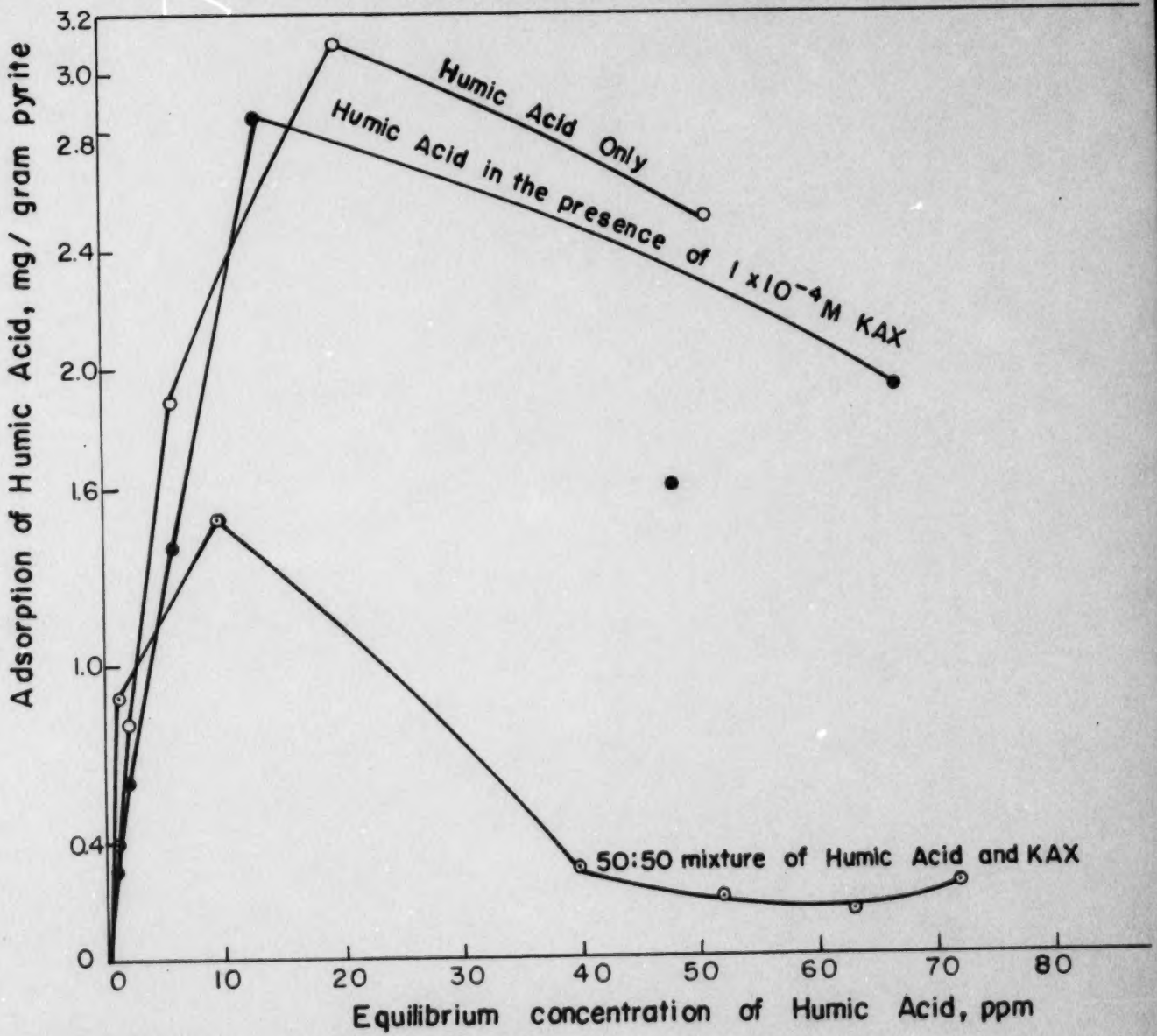
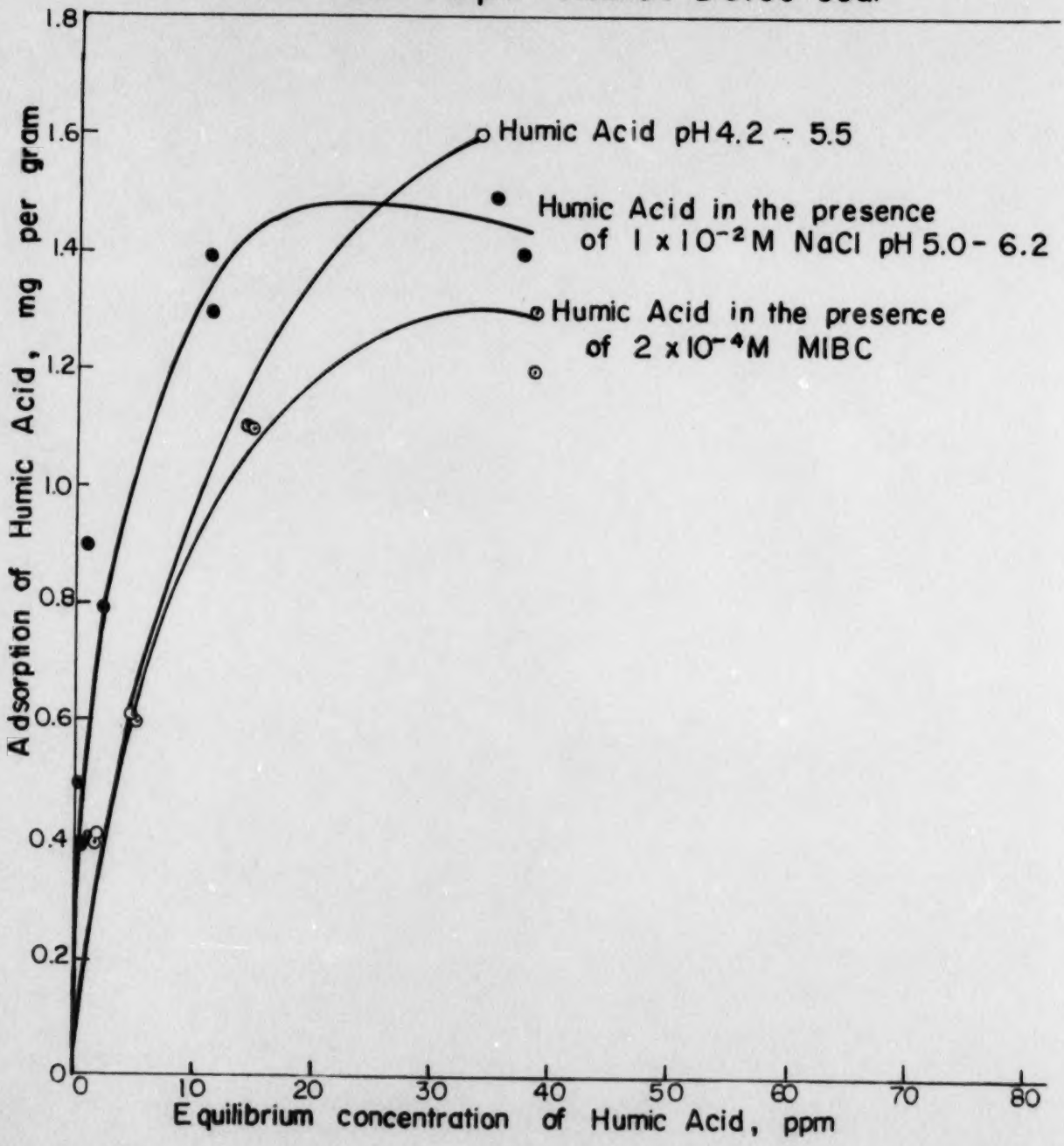


Fig. 29 Adsorption isotherm of Humic Acid on -75 μm cleaned Devco coal



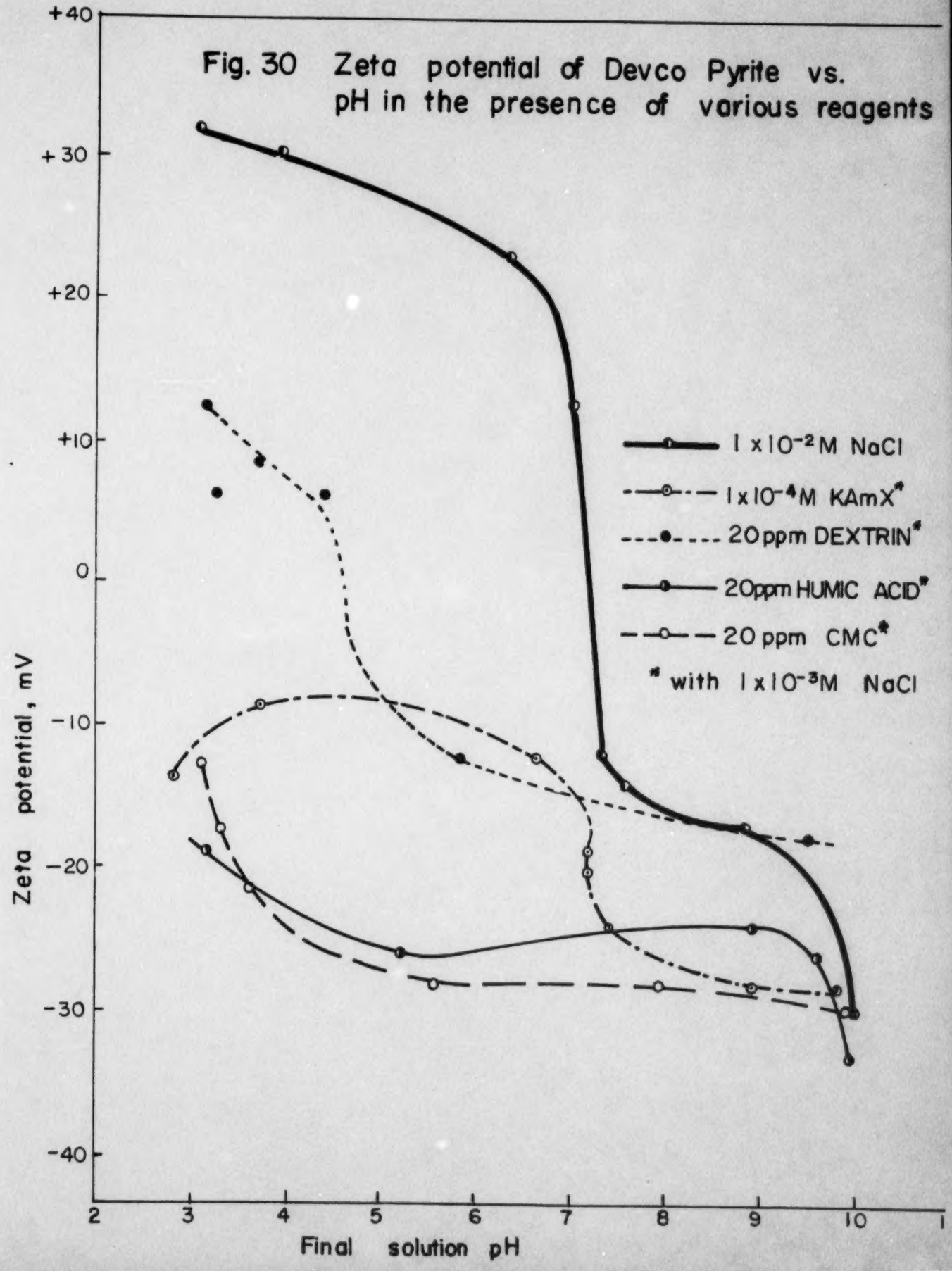
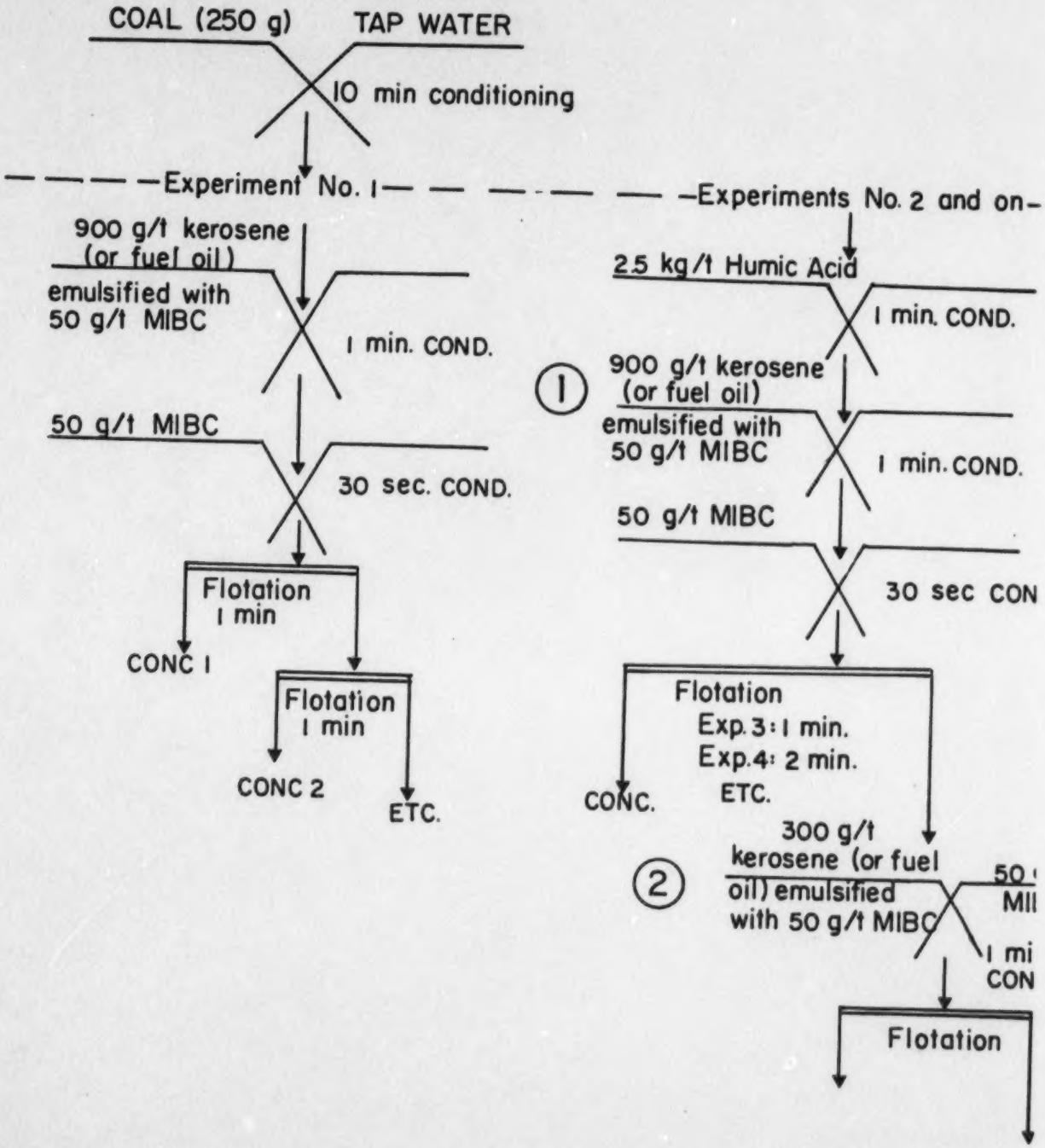


Fig. 30 Zeta potential of Devco Pyrite vs. pH in the presence of various reagents

Fig. 31 Schematic illustration of the batch flotation experiments procedure



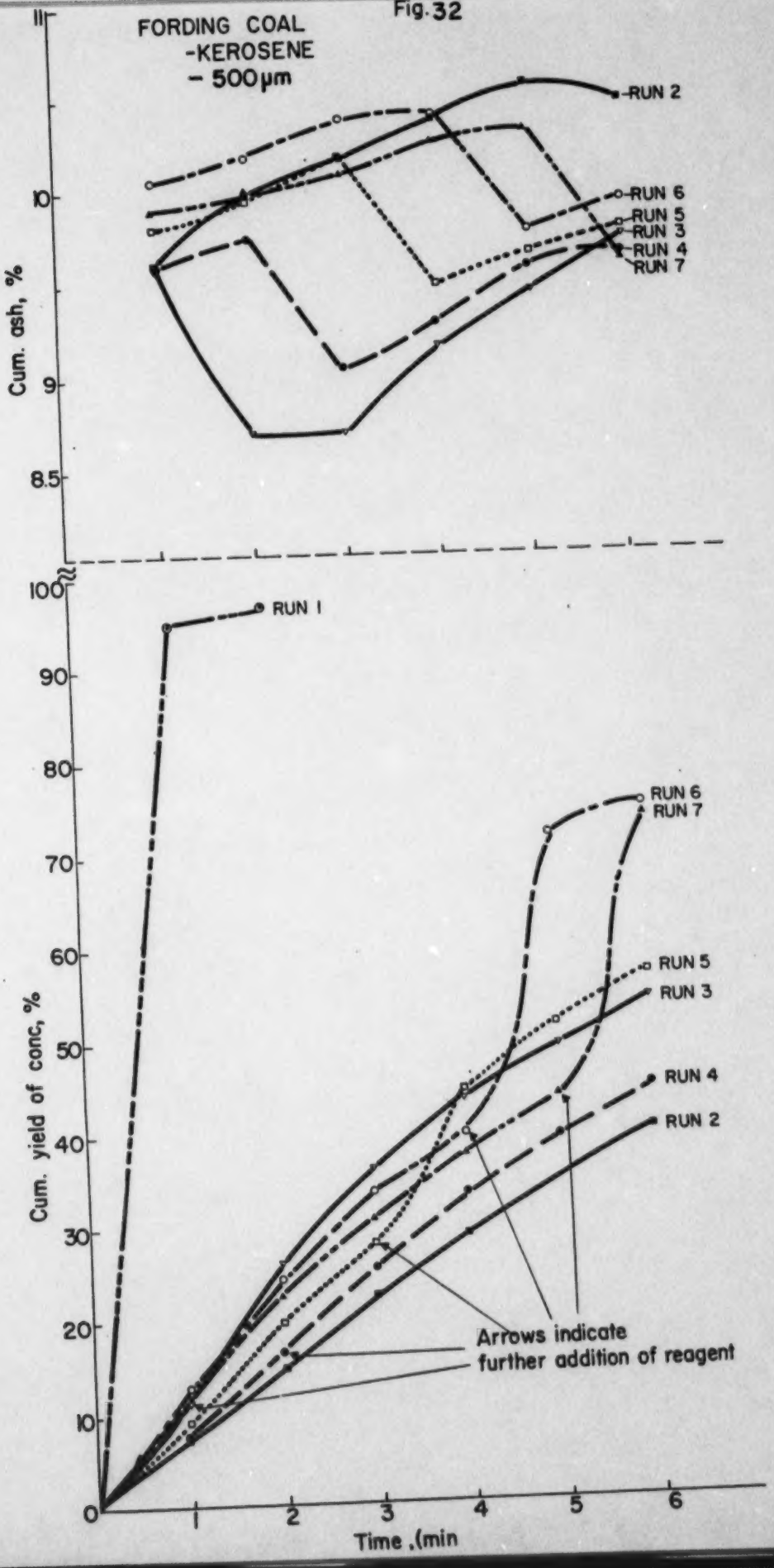

FORDING COAL
-KEROSENE
- 500µm
Fig.32
Cum. ash, %
11
10
9
8.5
RUN 2
RUN 6
RUN 5
RUN 3
RUN 4
RUN 7
Cum. yield of conc, %
100
90
80
70
60
50
40
30
20
10
0
RUN 1
RUN 6
RUN 7
RUN 5
RUN 3
RUN 4
RUN 2
Arrows indicate
further addition of reagent
1
2
3
4
5
6
Time ,(min

Fig. 33 FORDING COAL -500 Am
4:1 No. 2 & No. 6 FUEL OILS

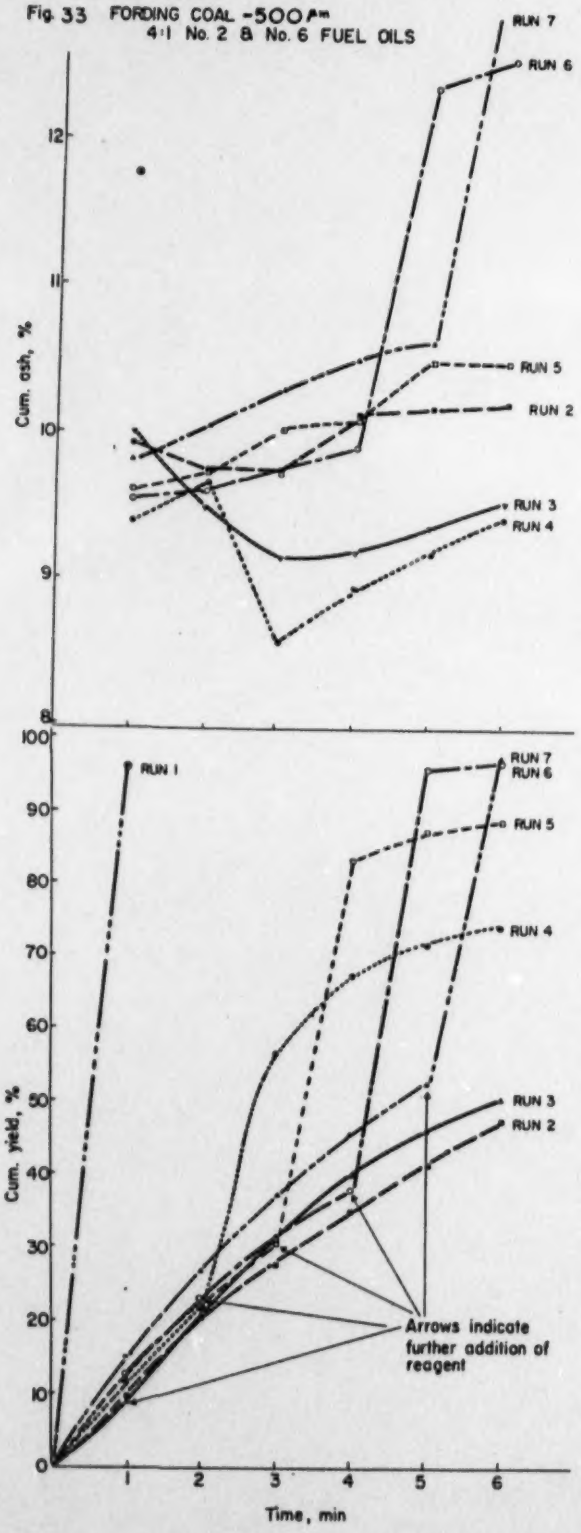


Fig. 34

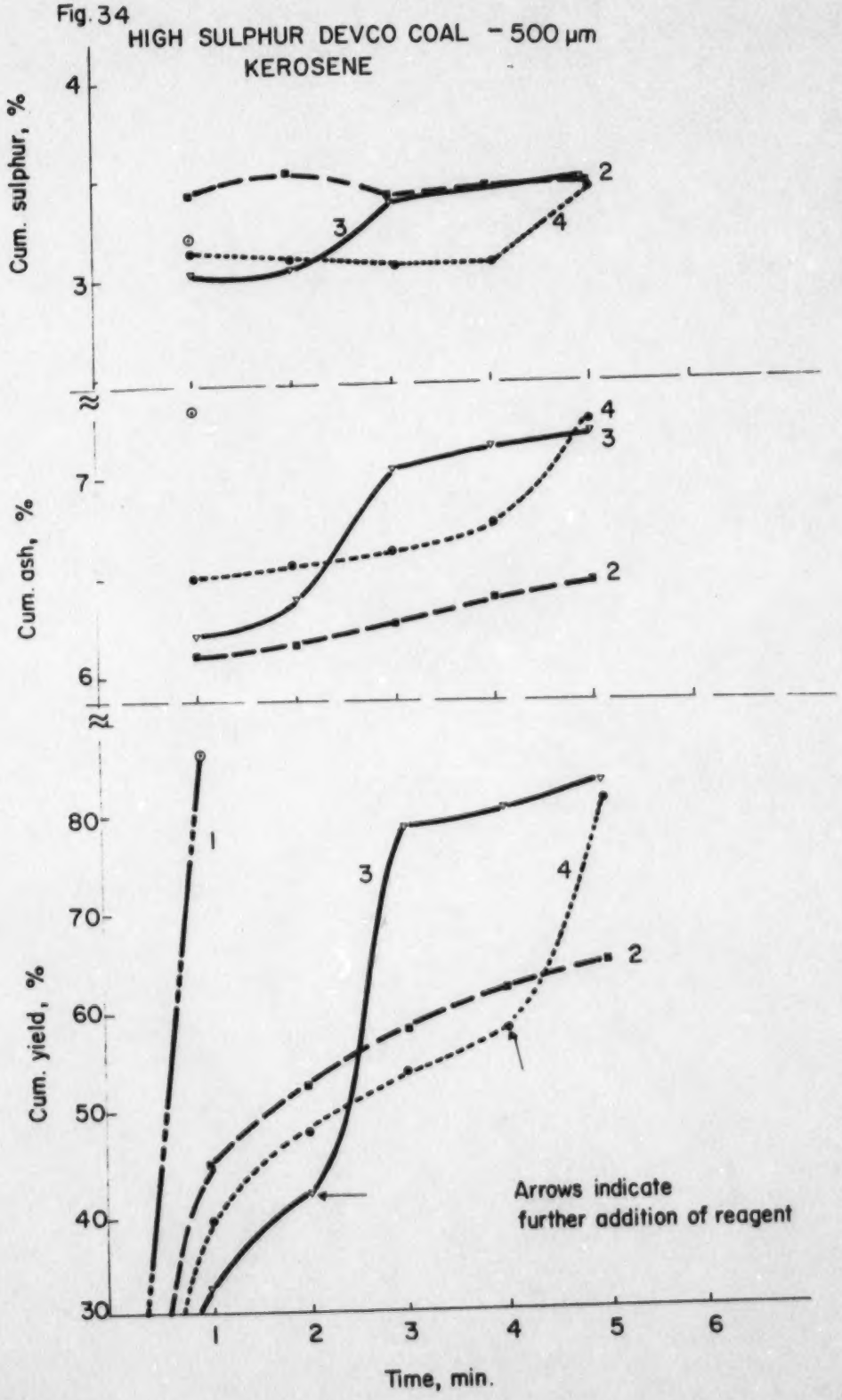

HIGH SULPHUR DEVCO COAL – 500 µm
KEROSENE
Cum. sulphur, %
Cum. ash, %
Cum. yield, %
Time, min.
Arrows indicate
further addition of reagent
1
2
3
4

Fig. 35 HIGH SULPHUR DEVCO COAL -500 μm
4:1 No.2 & No.6 OIL

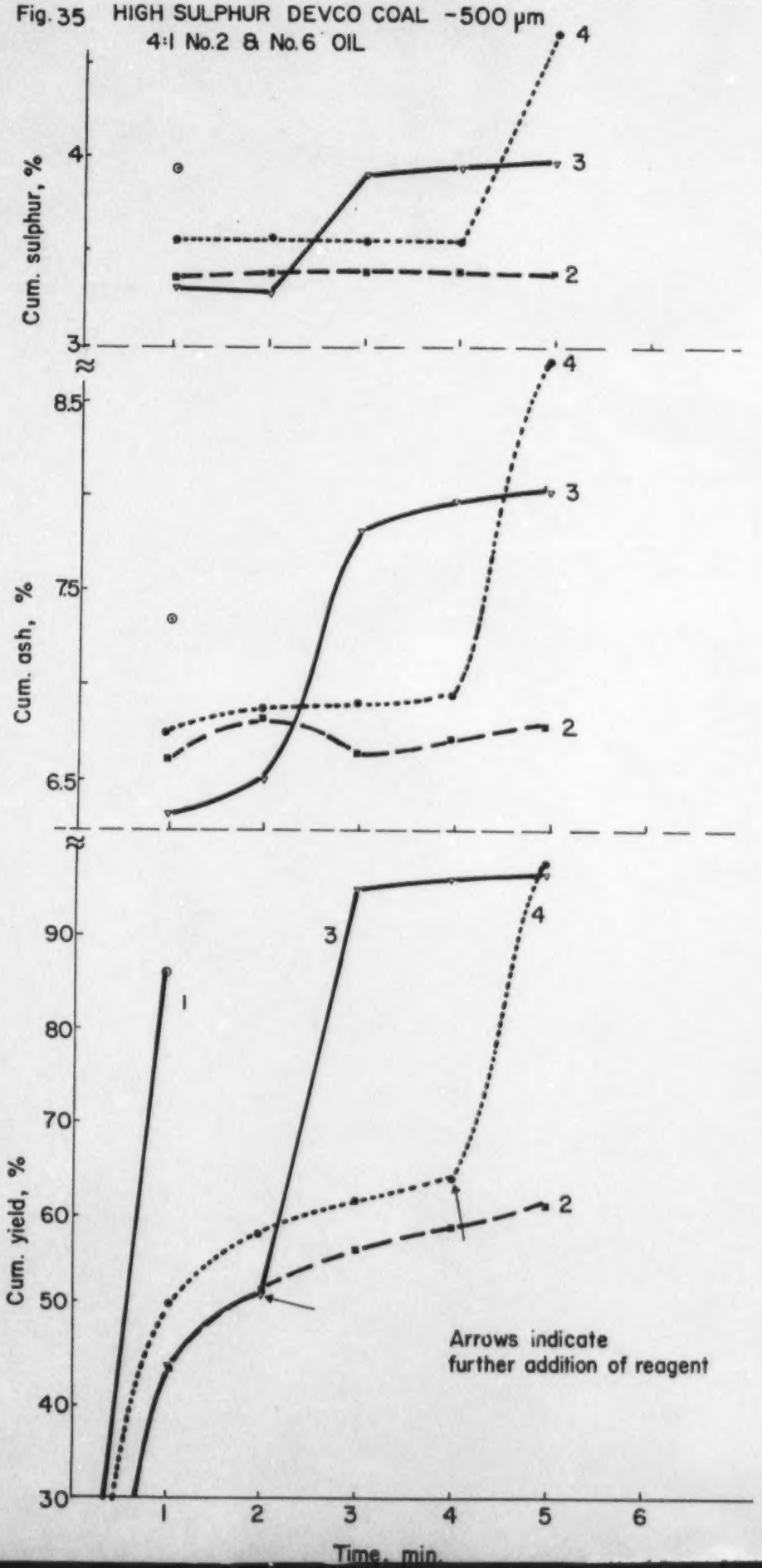
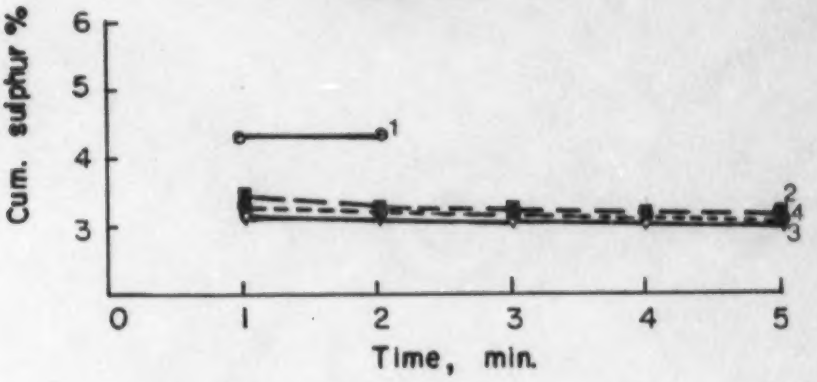
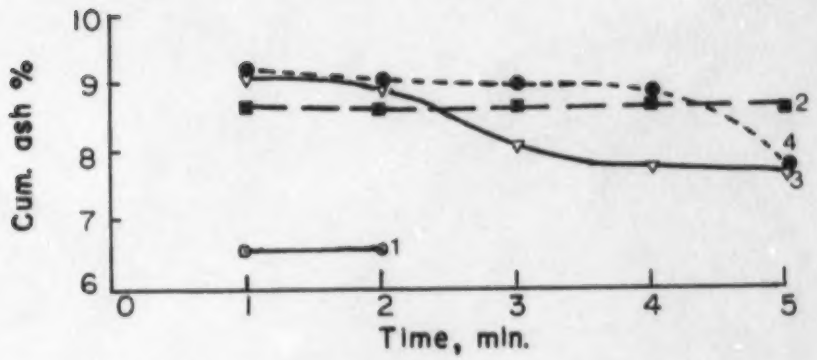


Fig. 36 HIGH SULPHUR DEVCO COAL - 200 µm
KEROSENE





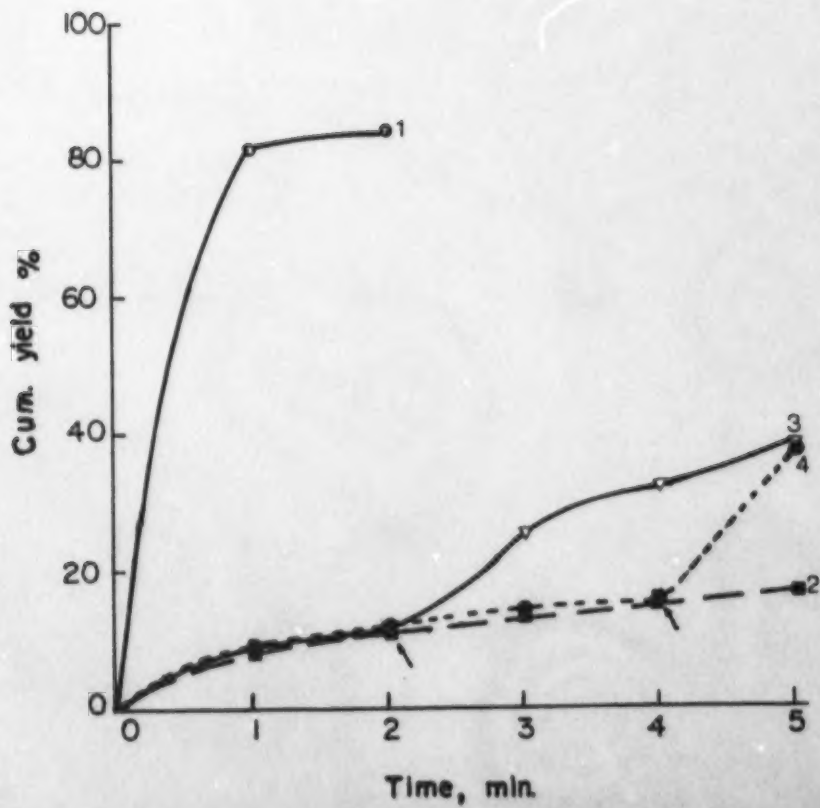
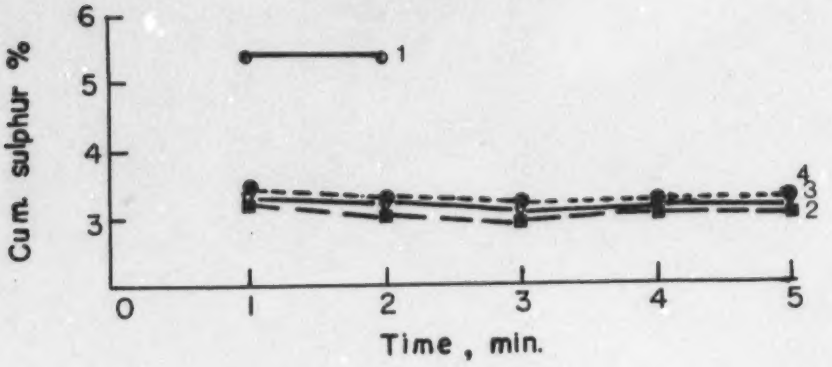
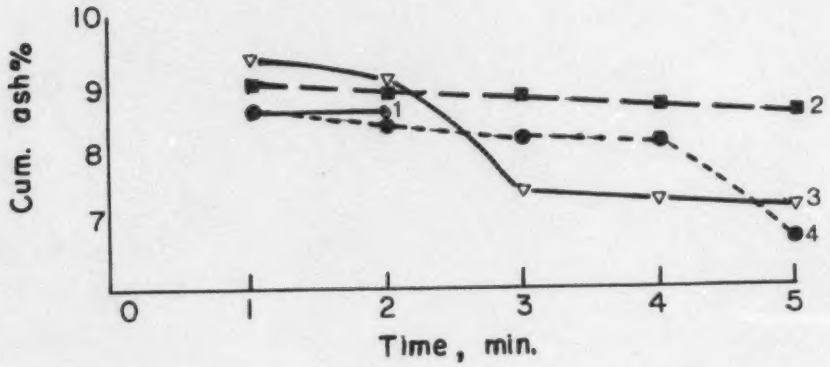


Fig. 37 HIGH SULPHUR DEVCO COAL - 200 μm
GULF FUEL OIL





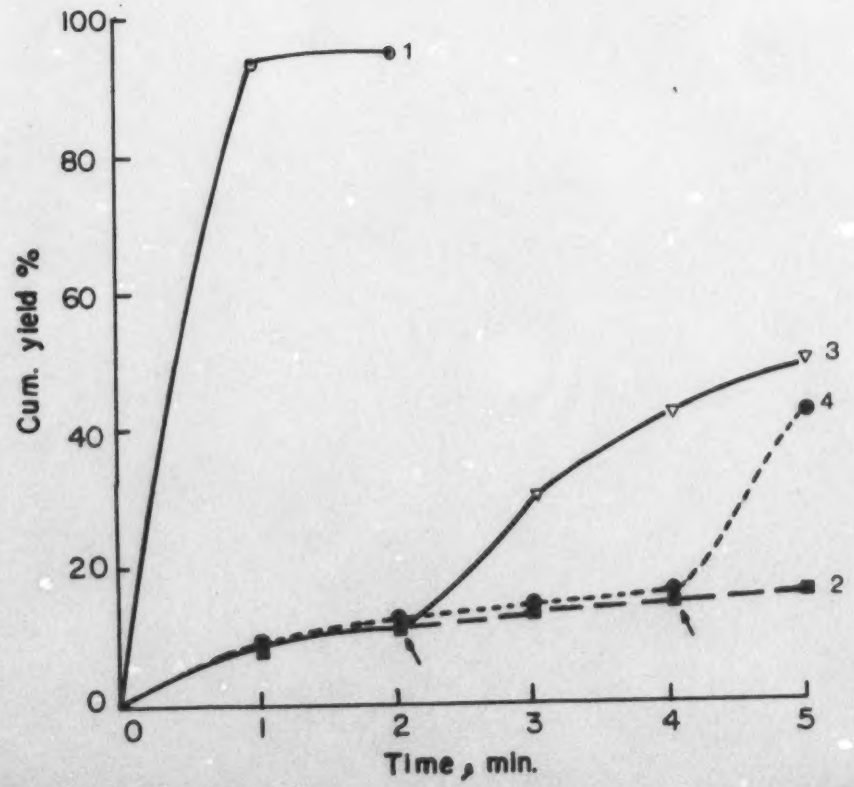
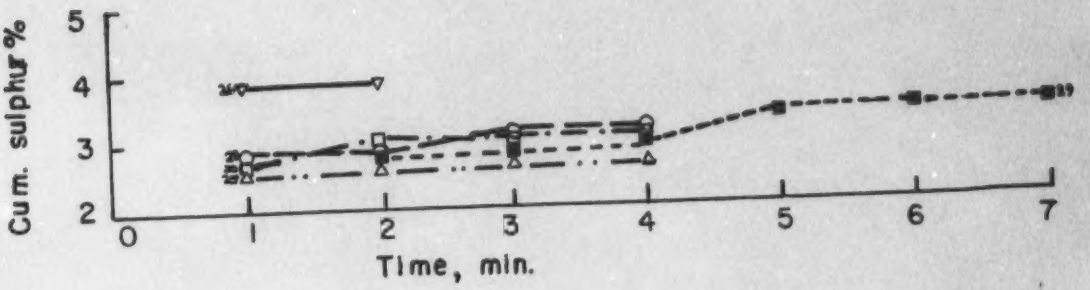
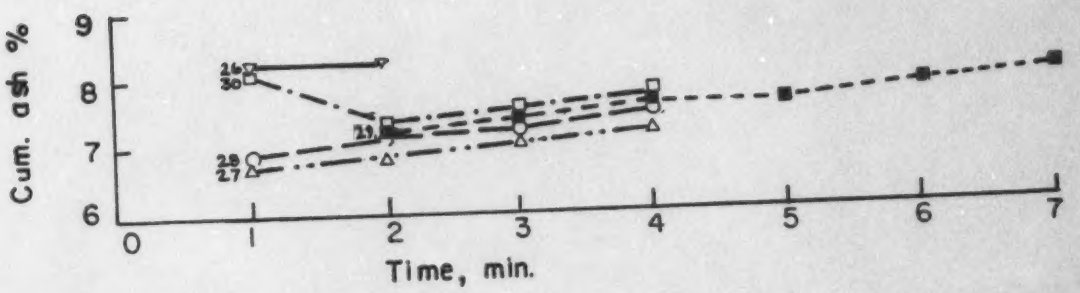


Fig. 38 HIGH SULPHUR DEVCO COAL -75 μm
KEROSENE





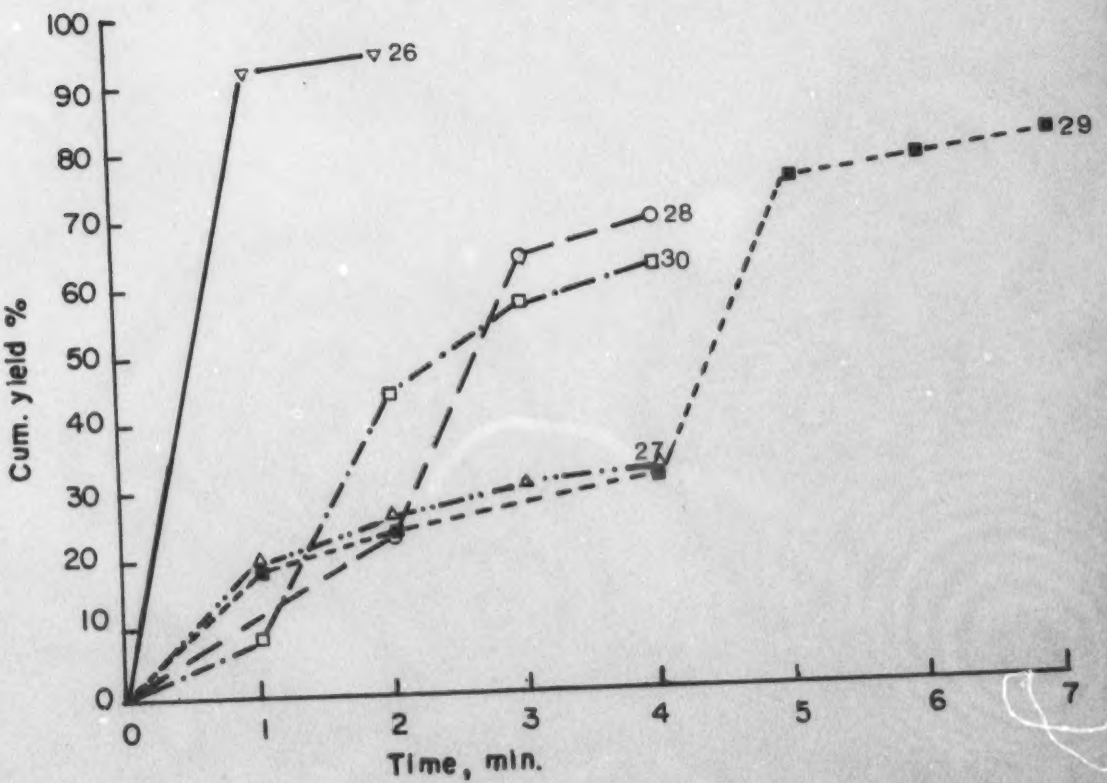


Fig.39 Schematic illustration of the batch flotation experiments procedure

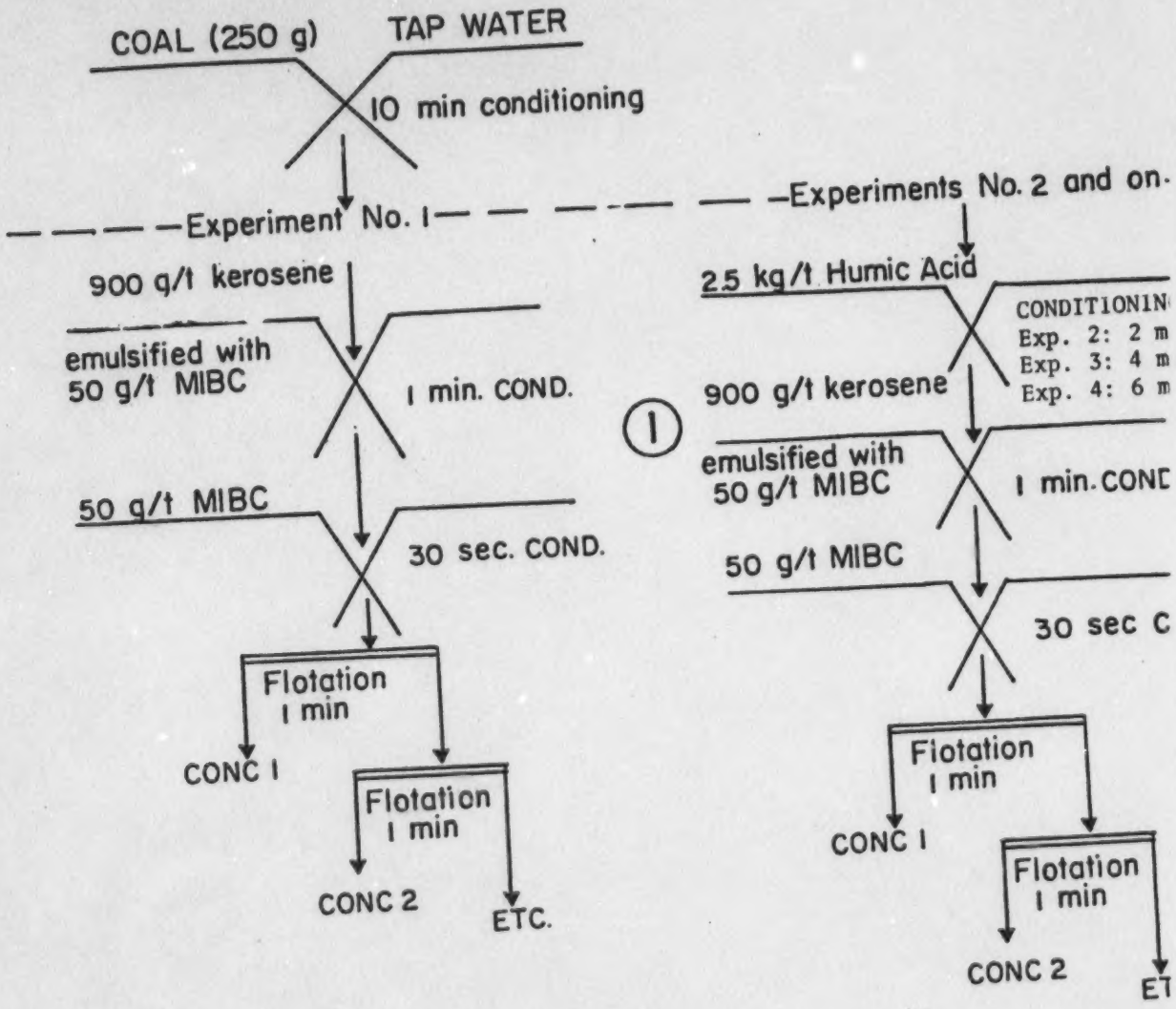


Fig. 40 FLOTATION OF HIGH SULPHUR DEVCO -200 µm COAL WITH HUMIC ACID ADDED BEFORE 300g/t KEROSENE AND 100 g/t MIBC

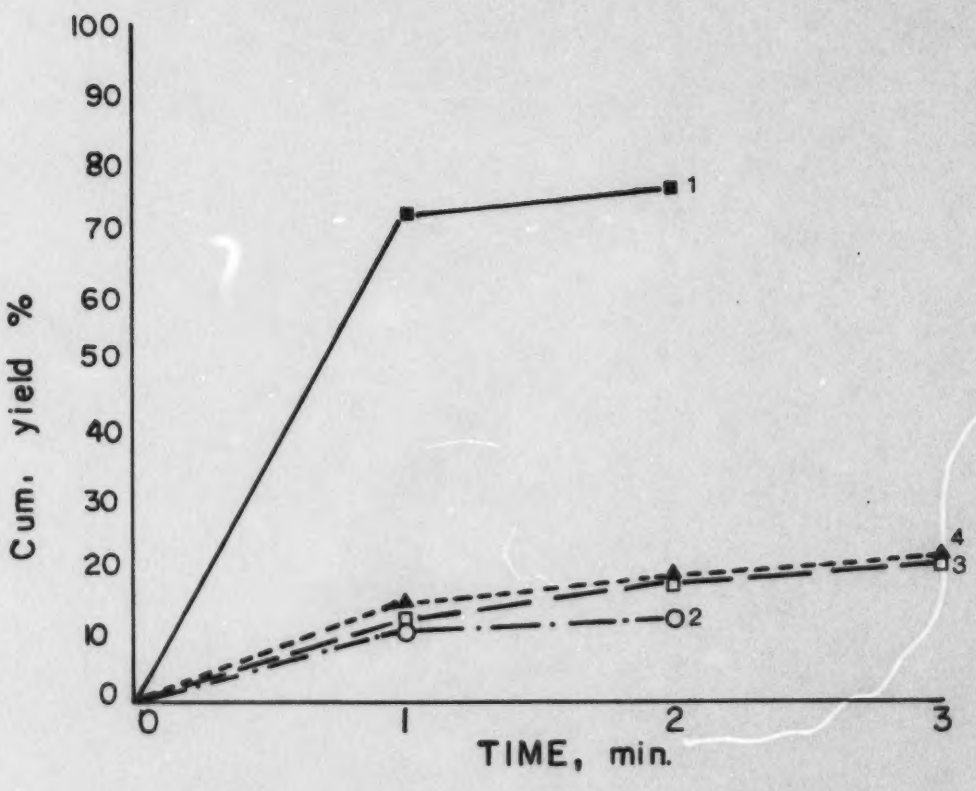


Fig. 41 FLOTATION OF HIGH SULPHUR DEVCO -200 um COAL WITH HUMIC ACID ADDED BEFORE 900g/t KEROSENE AND 100g/t MIBC

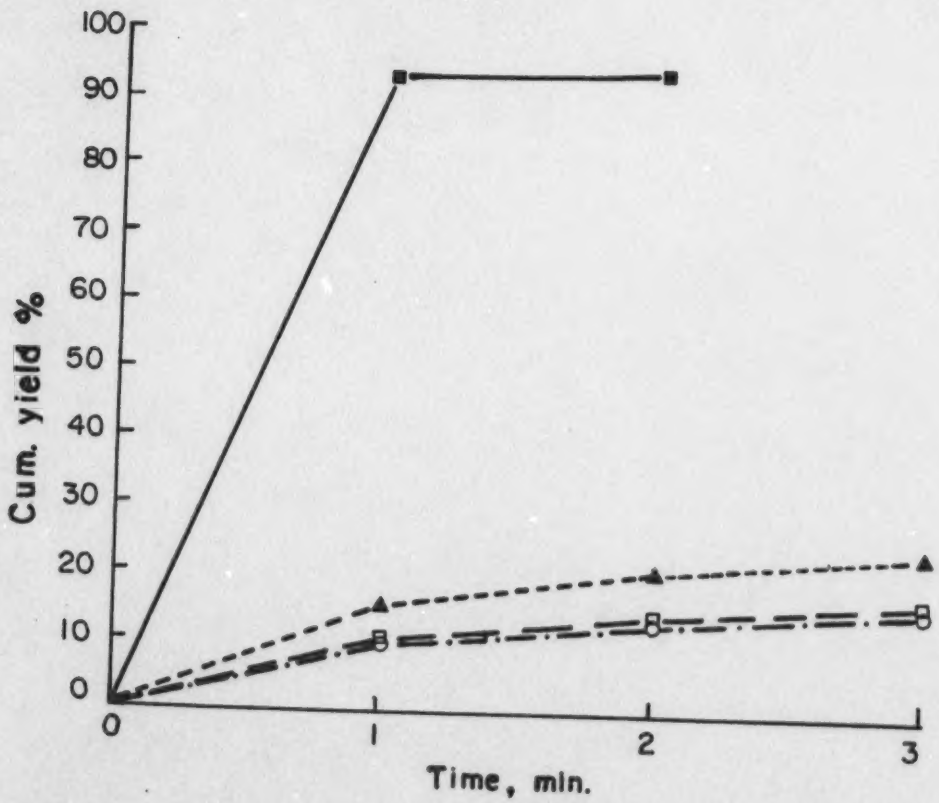


Fig. 42 FLOTATION OF -75um DEVCO COAL (DRY GRIND) WITH 400g/t MIBC AND 100g/t CMC

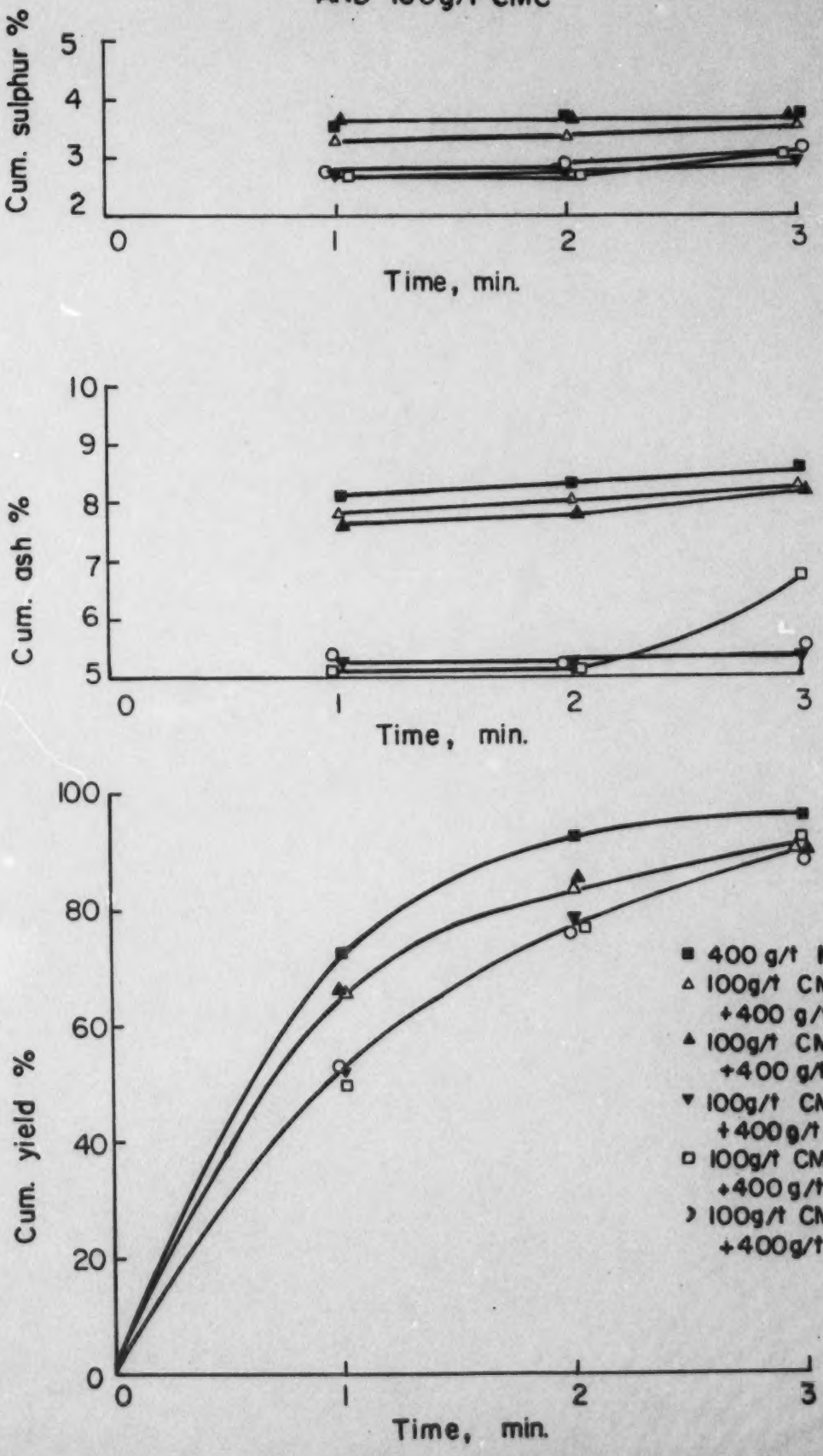
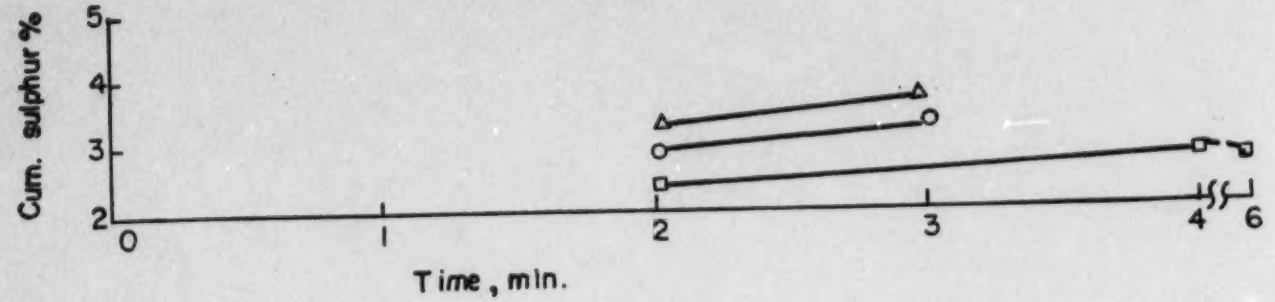
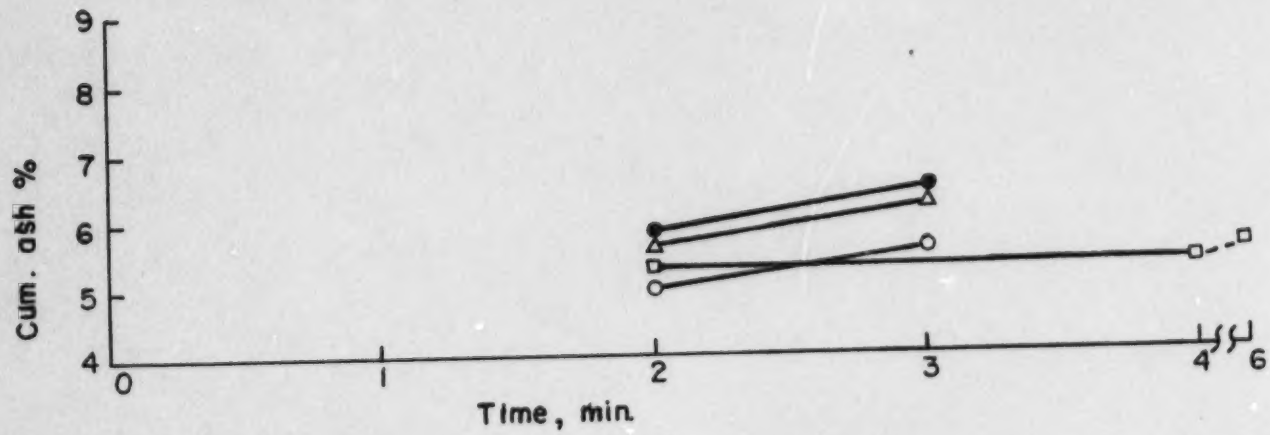


Fig. 43 FLOTATION OF -75 μm DEVCO COAL (DRY GRIND) WITH STAGE ADDITION OF REAGENTS





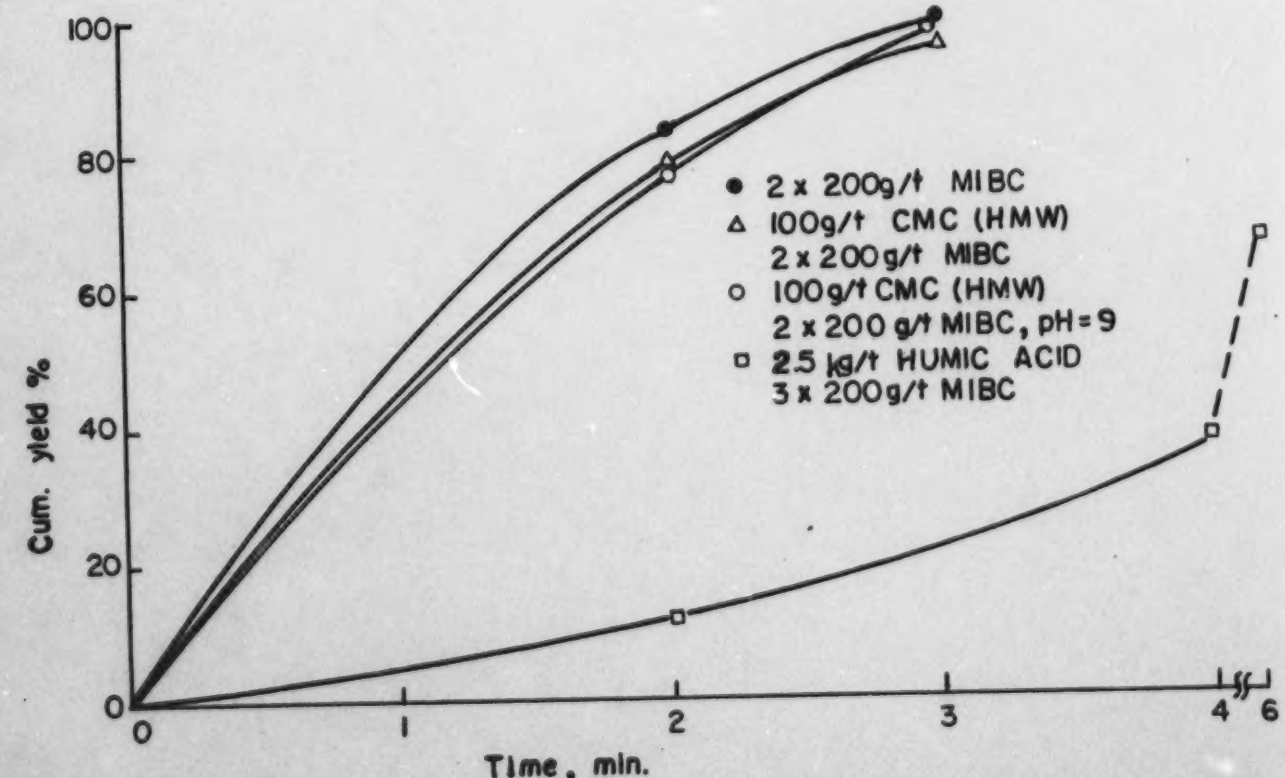


Fig.44 FLOTATION OF -75um DEVCO COAL WITH HUMIC ACID, KEROSENE, AND MIBC. AFTER WET OR DRY GRIND

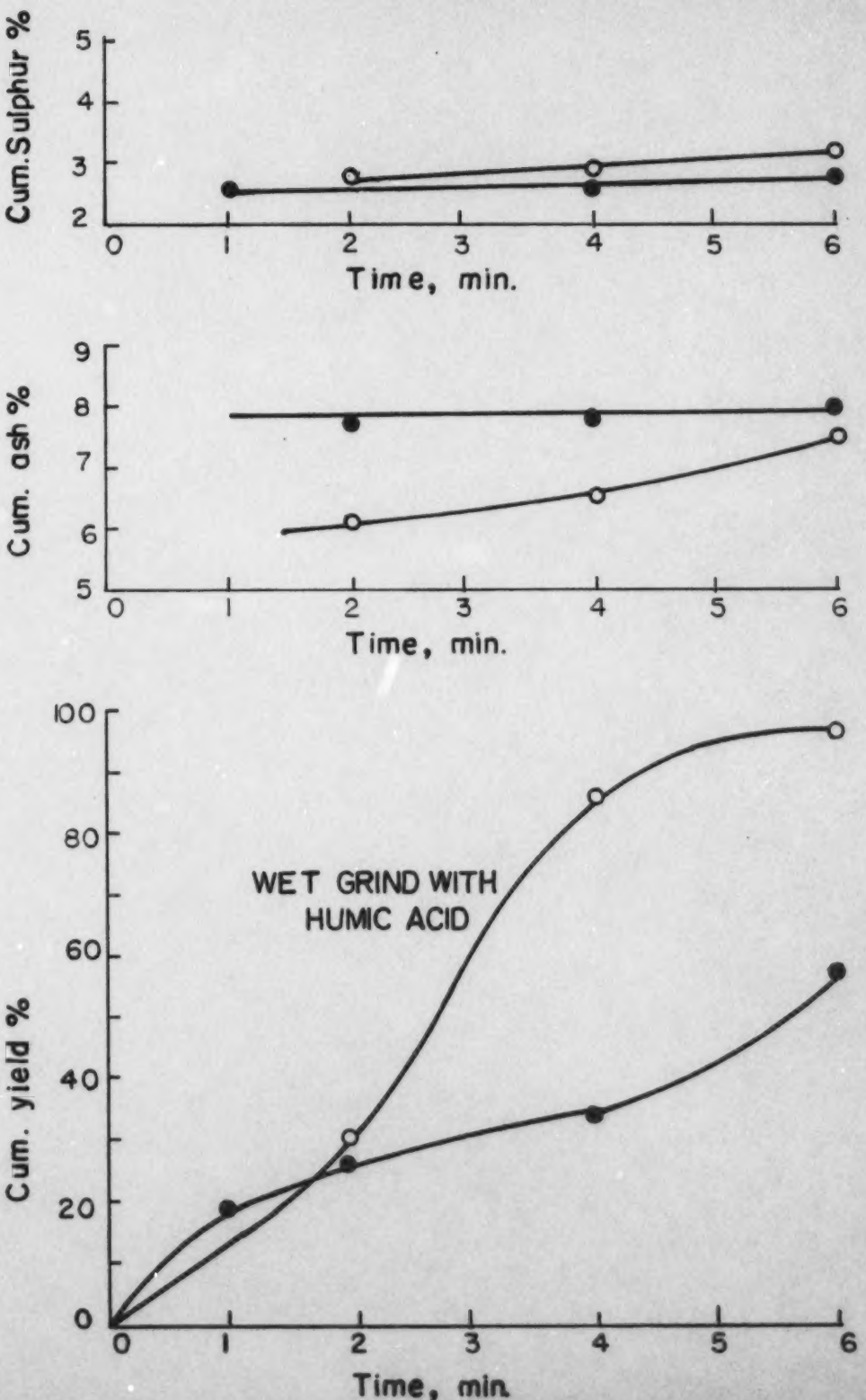


TABLE 1

Particle size, μm	% Weight	% Assay	
		Ash	S_T
DEVCO COAL -500 μm			
-500 +425	12.44	11.75	6.4
-425 +300	20.19	11.71	6.7
-300 +212	17.58	10.41	5.7
-212 +150	10.95	13.00	6.7
-150 +106	9.82	11.95	6.3
-106 + 75	7.23	12.77	6.3
- 75 + 45	6.36	11.10	6.2
- 45	15.42	15.50	5.2
DEVCO COAL -212 μm			
-212 +150	24.46	10.80	6.4
-150 +106	19.70	10.01	6.7
-106 + 75	15.63	11.51	6.8
- 75 + 45	11.00	7.40	5.3
- 45	31.32	12.55	4.7
DEVO COAL -75 μm			
- 75 + 53	13.28	10.86	5.65
- 53 + 38	20.59	9.8	4.93
- 38	66.13	9.3	4.15

TABLE 2

DEVCO COAL - 500 µm

Size Fraction µm	Vitrinite	Inerts	Semi-inerts	Liptinite	Total Pyrite	Non-liberated Pyrite
500-425	67.26	12.21	3.62	12.12	4.79	3.37
425-300						
300-212						
212-150	81.04	6.87	4.00	2.79	5.28	2.0
150-106	78.47	5.79	4.05	4.42	7.26	2.6
106- 75	72.35	7.32	2.63	8.72	8.97	1.39
75- 45	79.28	8.14	2.16	4.91	5.51	1.08
-45	77.80	7.51	6.23	2.23	6.00	2.07

PYRITE FORMS

	Liberated, %			Non-Liberated, %			
Size Fraction µm	Massive	Framboidal	Blebs	Massive	Framboidal	Blebs	Non-liberated / Total Pyrite
500-425	29.82	-	1.75	19.30	42.11	8.97	68.42
212-150	49.50	8.57	-	12.86	24.29	5.71	42.86
150-106	59.49	1.26	3.79	8.86	15.19	11.39	35.44
106- 75	75.23	7.33	0.92	1.83	10.09	3.67	15.60
75- 45	80.43	-	-	-	10.87	8.16	19.57
-45	-	6.67	-	-	25.67	7.69	33.33

TABLE 3

DEVCO COAL -200 μm

Size Fraction μm	Vitrinite	Inerts	Semi-inerts	Liptinite	Total Pyrite	Non-liberated Pyrite
212-150	79.04	8.00	2.24	6.73	4.03	2.25%
150-106	81.29	7.89	1.75	3.95	5.12	2.48%
106- 75	79.65	5.74	4.54	5.20	4.87	1.95%
75- 45	85.49	6.41	1.18	3.40	3.53	0.65%
-45	84.04	3.16	5.21	3.80	5.62	1.11%

PYRITE FORMS

	Liberated, %			Non-Liberated, %			
Size Fraction μm	Massive	Framboidal	Blebs	Massive	Framboidal	Blebs	Non-liberated / Total Pyrite
212-150	36.11	-	-	19.44	25.00	19.44	63.89%
150-106	51.43	-	-	14.29	25.71	8.57	48.57%
106- 75	55.56	4.44	-	4.44	20.00	15.56	40.00%
75- 45	77.78	3.70	-	-	14.81	3.70	18.52%
-45	24.14	27.59	24.14	-	6.89	18.54	24.14%

TABLE 4

DEVCO COAL -75μm

Size Fraction μm	Vitrinite	Inerts	Semi-inerts	Liptinite	Total Pyrite	Non-liberated Pyrite
-75+53	74.95%	5.54	3.51	10.02	5.86	1.81%
-53-38	77.24%	6.98	2.19	8.88	4.69	0.90%
-38	80.61%	8.34	1.10	5.25	4.66	0.74

PYRITE FORMS

	Liberated, %			Non-Liberated, %			
Size Fraction μm	Massive	Framboidal	Blebs	Massive	Framboidal	Blebs	Non-liberated / Total Pyrite
75	67.27%	1.81	-	14.54%	9.09%	7.27%	30.90%
53	80.85%	-	-	8.51%	6.38%	4.25%	19.15%
38	34.21%	34.21%	15.79%	-	7.89%	7.89%	15.79%

TABLE 5 - REVERSE FLOTATION RESULTS WITH DEVCO -75 μm COAL

FLOTATION CONDITIONS / FLOTATION PRODUCTS	#35.400g/t MIBC; 400 g/t MIBC + 1 kg/t DEXTRIN + 450 g/t KAmX			#48.600g/t MIBC; 400 g/t MIBC +1 kg/t DEXTRIN + 500 g/t KAmX			#49.Wet Grind 800 g/t MIBC; 600 g/t MIBC + 1 kg/t DEXTRIN + 500 g/t KAmX		
	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %
CONCENTRATE (PYRITE)	3.96	9.65	4.9	11.57	5.4	3.8	7.53	4.15	2.05
PRIMARY TAILINGS	5.23	47.25	12.0	2.63	33.8	12.2	8.05	33.1	11.0
SECONDARY TAILINGS (CLEAN COAL)	90.81	7.6	3.3	85.69	5.8	3.85	84.42	6.9	3.25

TABLE 6. FLOTATION OF -500μm FORDING RIVER COAL WITH KEROSENE AND HUMIC ACID

CUMUL. FLOT. TIME	FLOT. PRODUCT	EXPERIMENT NO. 1 YIELD%	1 ASH %	2 YIELD%	2 ASH %	3 YIELD%	3 ASH %	4 YIELD%	4 ASH %	5 YIELD%	5 ASH %	6 YIELD%	6 ASH %	7 YIELD%	7 ASH %
1 min.	Conc. 1	94.9	11.9	7.4	9.6	11.4	9.6	7.4	9.6	9.0	9.8	12.8	10.05	11.5	9.9
2 min.	Conc. 2	0.7	25.65	6.8	10.4	14.6	8.0	8.8	9.85	10.9	10.1	11.4	10.3	11.0	10.1
3 min.	Conc. 3			8.0	10.5	10.2	8.7	9.1	7.8	8.0	10.7	9.1	10.9	7.6	10.3
4 min.	Conc. 4			6.5	11.1	7.1	11.5	7.7	10.1	16.4	8.3	6.4	10.4	7.2	11.0
5 min.	Conc. 5			6.1	11.4	5.6	11.7	6.0	11.2	6.9	10.7	31.9	9.0	6.3	10.7
6 min.	Conc. 6			4.9	9.9	4.9	12.5	5.2	10.2	5.3	10.9	3.2	13.8	29.5	8.6
	Tails	4.3	64.3	60.4	17.4	46.2	20.9	55.9	20.1	43.5	21.3	25.2	27.95	26.8	27.7

Flotation of Fording Coal with 900 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t of MIBC added directly to pulp. Exp. 1: no Humic Acid; Exp. 2: 2.5 kg/t Humic Acid added 1 min. before other reagents. Experiments 3 and after were all run with Humic Acid added twice before other reagents. Exp. 3; additional 300 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t MIBC added directly after 1 min. of flotation; Exp. 4; additional amount of reagents added after 2 mins. of flotation; Exp. 5; additional reagents added after 3 mins. of flotation; Exp. 6; additional reagents added after 4 mins. of flotation; Exp. 7: additional reagents added after 5 mins, of flotation.

TABLE 7. FLOTATION OF - 500μm FORDING RIVER COAL WITH GULF FUEL OILS AND HUMIC ACID

CUMUL. FLOT. TIME	FLOT. PRODUCT	EXPERIMENT NO. 1		2		3		4		5		6		7	
		YIELD%	ASH %	YIELD%	ASH %	YIELD%	ASH %	YIELD%	ASH %	YIELD%	ASH %	YIELD%	ASH %	YIELD%	ASH%
1 min.	Conc, 1	95.7	11.8	9.7	9.9	9.0	10,0	11.6	9.4	11.8	9.6	12.5	9.55	15.1	9.8
2 min.	Conc. 2			10.5	9.6	12,0	9,1	10.1	9.95	9.9	9.9	10,5	9.65	11.8	10.4
3 min.	Conc. 3			6.9	9.7	10,1	8,4	34.5	7.9	8.4	10.7	8.0	10,1	10.0	11.2
4 min.	Conc. 4			7.3	11.65	8,4	9,3	10.7	10.8	52,6	10.1	6.4	10.7	7.9	11,1
5 min.	Conc. 5			6.5	10,3	5,9	10.8	4.1	13.3	3.9	19,1	57.5	13.95	6,9	11,4
6 min.	Conc, 6			6,0	10.5	4,1	11.4	2.6	15,1	1,2	72.2	1.0	30.6	44,5	16.6
	Tails	4.3	65.7	53.2	18.43	5.05	18,4	26.5	28.8	12.1	9.7	4.0	45,9	3,8	40.6

Flotation of Fording Coal with 900 g/t of fuel oil (Gulf Oil; 75% No, 2 and 25% No. 6) emulsified with 50 g/t MIBC and 50 g/t MIBC added directly to the pulp. Exp, 1; no Humic Acid; Exp, No, 2: 2.5 kg/t Humic Acid added 1 min. before other reagents, Experiments No. 3 and after were all run with Humic Acid added 1 min, before other reagents; Exp. 3 additional 300 g/t fuel oil emulsified with 50 g/t MIBC and 50 g/t MIBC added directly after 1 min. of flotation: Exp, 4: additional amount of reagents added after 2 mins, of flotation; Exp. 5: additional reagents added after 3 mins. of flotation; Exp, 6: additional reagents added after 4 mins. after flotation, etc,

TABLE 8. FLOTATION OF DEVCO - 500 μm COAL WITH KEROSENE AND HUMIC ACID

CUMUL. FLOT. TIME	FLOT. PRODUCT	EXPERIMENT NO. 1			2			3			4		
		YIELD%	ASH %	S %	YIELD%	ASH %	S %	YIELD%	ASH %	S %	YIELD%	ASH %	S %
1 min,	Conc. 1	88,6	7,8	3,2	44.5	6.1	3.4	32,4	6,2	3,05	39.1	6.5	3.1
2 min.	Conc. 2				8.2	6.45	4.2	9.6	7.0	3.06	9.1	6.8	2.96
3 min.	Conc. 3				5.7	7.25	2.5	36,7	7,8	3.85	5.8	7.2	3,00
4 min.	Conc. 4				3,7	8,4	3,85	2.2	10.85	5.02	4,0	8,6	3.4
5 min.	Conc. 5				2.8	8.35	3,9	2,6	9,7	3.7	23,4	8.5	4.45
	Tails	11.4	26.1	12,1	35.2	15.1	14,9	16.5	23.2	9,75	18.5	12.5	9.87

Flotation of Devco Coal with 900 g/t kerosene emulsified with 50 g/t MIBC, and 50 g/t MIBC added directly to the pulp. Exp. 1; no Humic Acid; Exp. 2; 2.5 kg/t Humic Acid added 1 min. before other reagents. Experiment 3 was run in the same way as Exp. 2, but after 2 mins. of flotation 300 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t MIBC were added; Exp. 4 - as Exp. 2, but 300 g/t emulsified kerosene with 50 g/t MIBC and 50 g/t MIBC were added after 4 mins. of flotation.

TABLE 9. FLOTATION OF DEVCO -500μm COAL WITH GULF FUEL OILS AND HUMIC ACID

CUMUL. FLOT. TIME	FLOT. PRODUCT	EXPERIMENT NO. 1			2			3			4		
		YIELD%	ASH %	S %	YIELD%	ASH %	S %	YIELD%	ASH %	S %	YIELD%	ASH %	S %
1 min.	Conc. 1	85.8	7.3	3.9	44.4	6,6	3,35	44.1	6.3	3.3	50.8	6,75	3.55
2 min.	Conc. 2				7.9	7.8	3.45	7.4	7.7	3.1	7.2	7.7	3.6
3 min.	Conc. 3				4.1	8.1	3.45	43,1	9,4	4,7	3,4	7,5	3,4
4 min.	Conc. 4				2.4	8.7	3.5	1.0	23,0	7,25	2.3	8.2	3.6
5 min.	Conc. 5				2,1	8.7	3.5	0.3	24,2	6.5	33.0	12,2	16.9
	Tails	14.2	23.1	10,6	39.1	12.5	6.5	4.1	43,65	18.25	3,4	43.8	15.8

Flotation of Devco Coal with 900 g/t Gulf Fuel Oil (75% No. 2 Oil + 25% No, 6 oil) emulsified with 50 g/t MIBC and 50 g/t MIBC added directly to the pulp. Exp. 1: no Humic Acid; Exp. 2: 2.5 kg/t Humic Acid added 1 min. before other reagents. Exp. 3 was run in the same way as No. 2 but after 2 mins. of flotation 300 g/t fuel oil emulsified with 50 g/t MIBC and 50 g/t MIBC were added; Exp, 4 - as Exp. 2, but 300 g/t emulsified fuel oil with 50 g/t MIBC and 50 g/t MIBC were added after 4 mins, of flotation.

TABLE 10. FLOTATION OF DEVCO -200 μm COAL WITH KEROSENE AND HUMIC ACID

CUM. FLOT. TIME	FLOT. PRODUCT	EXPERIMENT NO.											
		1			2			3			4		
		Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%
1 Min.	Conc. 1	82.42	6.6	4.3	9.81	8.7	3.45	8.81	9.1	3.2	9.23	9.2	3.35
2 Min.	Conc. 2	1.65	12.4	4.8	2.50	8.4	2.75	2.92	8.4	2.8	2.55	8.5	2.95
3 Min.	Conc. 3				2.07	8.6	2.8	13.61	7.4	3.15	2.10	8.7	2.75
4 Min.	Conc. 4				1.57	8.6	2.8	7.51	6.8	2.85	1.24	8.3	2.47
5 Min.	Conc. 5				1.19	8.8	2.77	5.51	7.1	2.87	22.36	7.0	3.05
	TAILS	15.93	32.15	11.1	82.86	11.15	5.8	61.64	13.15	7.45	62.53	13.75	7.4

Flotation of DEVCO -200 μm coal with 900 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t MIBC added directly to pulp. Exp. 1: no Humic Acid; Exp. 2: 2.5 kg/t Humic Acid added 1 min. before other reagents; Exp. 3: same as No. 2 but additional 300 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t MIBC added directly after 2 min. of flotation; Exp. 4: same as No. 2 but additional 300 g/t kerosene emlsified with 50 g/t MIBC and 50 g/t MIBC added directly after 4 min. of flotation.

TABLE 11. FLOTATION OF DEVCO -200 μm COAL WITH FUEL OIL AND HUMIC ACID

CUM. FLOT TIME	FLOT. PRODUCT	EXPERIMENT NO.											
		1			2			3			4		
		Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%
1 Min.	Conc. 1	94.73	8.6	5.4	8.80	9.0	3.3	8.22	9.4	3.2	9.93	8.6	3.45
2 Min.	Conc. 2	1.08	10.9	4.5	2.72	8.5	2.9	3.06	8.1	2.8	2.92	7.7	2.8
3 Min.	Conc. 3				1.99	8.3	2.5	18.93	6.45	2.9	1.89	6.95	2.45
4 Min.	Conc. 4				1.67	7.5	2.6	12.45	7.0	3.5	1.53	7.05	2.75
5 Min.	Conc. 5				1.02	7.0	2.4	7.51	6.6	3.4	26.26	5.85	3.2
	TAILS	4.19	59.35	17.7	83.80	10.9	5.3	49.84	14.7	7.25	57.47	12.7	6.9

Flotation of DEVCO - 200 μm coal with 900 g/t Gulf fuel oil (#2 and #6 4 : 1) emulsified with 50 g/t MIBC and 50 g/t MIBC added directly to pulp. Exp. 1: no Humic Acid; Exp. 2: 2.5 kg/t Humic Acid added 1 min. before other reagents; Exp. 3: same as Exp. 2 but additional 300 g/t fuel oil emulsified with 50 g/t MIBC and 50 g/t MIBC added directly after 2 min. of flotation; Exp. 4: same as No. 2 but additional 300 g/t fuel oil emulsified with 50 g/t MIBC and 50 g/t MIBC added directly after 4 min. of flotation.

TABLE 12. FLOTATION OF DEVCO -75 μm COAL WITH KEROSENE AND HUMIC ACID

	FLOT. PRODUCT	EXPERIMENT NO.															
		1			2			3			4			5			
		Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%	
	CONC. 1	90.89	8.1	3.8	19.58	6.6	2.5	17.90	6.8	2.75	23.70	7.1	2.7	7.73	8.1	2.65	
	CONC. 2	2.73	8.2	4.65	6.03	7.3	2.55	5.76	7.7	2.70	6.38	8.9	2.9	36.19	7.1	3.05	
	CONC. 3				3.61	8.35	2.8	39.59	7.2	3.20	43.20	7.5	3.6	12.74	8.1	3.05	
	CONC. 4				2.63	8.4	2.85	5.35	10.5	3.60	3.60	12.2	3.65	4.39	9.9	3.3	
	CONC. 5										1.52	14.3	3.7				
	TAILS	6.38	39.9	7.7	68.16	11.3	4.45	31.41	15.8	5.7	21.60	17.9	6.3	38.95	13.9	5.2	

Flotation of DEVCO - 75 μm coal with 900 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t MIBC added directly to pulp.
Exp. 1: no Humic Acid;
Exp. 2: 2.5 kg/t Humic Acid added 1 min. before other reagents;
Exp. 3: same as No. 2 but additional 300 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t MIBC added directly after 1 min. of flotation;
Exp. 4: same as No. 2 but additional 300 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t MIBC added directly after 2 min. of flotation;
Exp. 5: same as No. 2 but additional 300 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t MIBC added directly after 4 min. of flotation.

TABLE 13. FLOTATION OF DEVCO -200 μm COAL WITH KEROSENE ANDHUMIC ACID

CUM. FLOT. TIME	FLOT. PRODUCT	EXPERIMENT NO.											
		1			2			3			4		
		Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%
1 Min.	Conc. 1	71.78	5.71	3.75	10.22	7.57	3.3	11.58	6.25	2.65	14.19	5.80	2.6
2 Min.	Conc. 2	4.20	7.71	3.95	2.21	8.13	2.8	5.55	7.31	2.9	4.59	6.88	2.8
3 Min.	Conc. 3							3.03	7.35	2.9	2.69	7.63	3.0
	TAILS	24.02	15.41	9.48	87.57	11.63	8.67	79.84	11.93	6.2	78.53	9.46	5.3

Flotation of DEVCO -200 μm coal with 300 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t MIBC added directly to pulp. Exp. 1: no Humic Acid; Exp. 2: 2.5 kg/t Humic Acid added 2 min. before other reagents; Exp. 3: 2.5 kg/t Humic Acid added 4 min. before other reagents; Exp. 4: 2.5 kg/t Humic Acid added 6 min. before other reagents.

TABLE 14. FLOTATION OF DEVCO -200 μm COAL WITH KEROSENE AND HUMIC ACID

CUM. FLOT TIME	FLOT. PRODUCT	EXPERIMENT NO.											
		1			2			3			4		
		Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%	Yield%	Ash%	S%
1 Min.	Conc. 1	93.54	7.07	5.05	9.58	5.21	2.55	10.02	5.20	2.65	15.11	5.07	2.6
2 Min.	Conc. 2	0.58	8.61	7.7	3.65	5.09	2.55	4.09	4.88	2.67	5.42	4.85	2.5
3 Min.	Conc. 3				2.44	4.69	2.4	2.66	4.83	2.4	3.33	4.92	5.47
	TAILS	5.89	24.34	11.35	84.33	10.16	5.9	83.24	8.60	5.03	76.14	9.25	2.5

Flotation of DEVCO -200 μm coal with 900 g/t kerosene emulsified with 50 g/t MIBC and 50 g/t MIBC added directly to pulp. Exp. 1: no Humic Acid; Exp. 2: 2.5 kg/t Humic Acid added 2 min. before other reagents; Exp. 3: 2.5 kg/t Humic Acid added 4 min. before other reagents; Exp. 4: 2.5 kg/t Humic Acid added 6 min. before other reagents.

TABLE 15. FLOTATION OF DEVCO - 75μm COAL WITH MIBC AND CMC

FLOT. PRODUCT	#31. 400 g/t MIBC			#33. 100 g/t CMC (HMW) 400 g/t MIBC			#34. 100 g/t CMC(LMW) 400 g/t MIBC			#36. 100 g/t CMC(HMW) 400 g/t MIBC;pH=7.5			#37. 100 g/t CMC(HMW) 400 g/t MIBC; pH=8			#38. 100 g/t CMC(LMW) 400 g/t MIBC; pH=9		
	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %
CONC. 1	72.36	8.1	3.5	64.52	7.8	3.3	66.39	7.6	3.6	51.44	5.2	2.7	50.41	5.1	2.75	52.59	5.32	2.75
CONC. 2	20.34	9.2	4.7	18.80	8.8	3.9	17.66	9.3	4.1	26.88	5.1	2.95	27.20	5.2	2.8	23.54	5.2	3.3
CONC. 3	3.17	16.5	4.25	7.65	11.7	5.15	6.70	12.2	4.7	12.30	7.3	4.4	14.54	16.45	4.3	12.54	7.3	4.25
TAILS	4.13	47.0	11.75	9.03	29.7	7.5	9.24	29.7	6.9	9.38	22.2	8.75	7.86	25.5	12.35	11.33	21.7	12.3

TABLE 16.

FLOTATION CONDITIONS / FLOTATION PRODUCTS	# 52. Stage addition of MIBC 2 x 200 g/t			#40. 100 g/t CMC (HMW) Stage add. MIBC 2 x 200 g/t			#41. 100 g/t CMC (HMW) Stage add. 2 x 200 g/t pH = 9			#42. 2.5 kg H.A., Stage add. 3 x 200 g/t MIBC		
	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %
CONC. 1	82.82	5.80	3.25	68.10	5.65	3.3	72.58	5.0	2.9	11.99	5.3	2.4
CONC. 2	15.24	10.05	6.1	26.97	7.65	4.45	26.35	7.3	4.4	25.86	5.5	3.0
CONC. 3										26.75	5.8	2.7
CONC. 4												
CONC. 5												
TAILS	1.94	40.05	15.2	4.95	25.1	9.0	1.07	60.0	19.3	35.39	8.0	4.4

TABLE 17. FLOTATION OF DEVCO -75 μm COAL WITH KEROSENE AND HUMIC ACID

FLOTATION CONDITIONS / FLOTATION PRODUCTS	# 32. 2.5 kg/t H.A. + 900 g/t kerosene + 100 g/t MIBC, blending; 300 g/t kerosene + 100 g/t MIBC; 100 g/t MIBC after 3rd conc.			# 46. Wet grinding with 2.5 kg/t H.A. + 900 g/t kerosene and 100 g/t MIBC; 600 g/t kerosene + 200 g/t MIBC; 200 g/tMIBC after 1st conc.					
	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %
C1	18.51	7.9	2.5	30.04	6.1	2.7			
C2	8.12	7.5	2.6	57.01	6.75	3.1			
C3	7.85	8.2	2.8	10.87	15.8	5.8			
C4	22.97	8.4	3.2						
C5									
TAILS	42.56	12.3	5.0	2.07	67.3	20.45			